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Implementation of Vertical Handoff Algorithm between IEEE802.11 WLAN and CDMA Cellular Network

Mary Narisetti

IMPLEMENTATION OF VERTICAL HANDOFF ALGORITHM BETWEEN IEEE802.11 WLAN AND CDMA CELLULAR NETWORK

by

MARY NARISETTI

Under the Direction of Yi Pan

ABSTRACT

Today's wireless users expect great things from tomorrow's wireless networks. These expectations have been fueled by hype about what the next generations of wireless networks will offer. The rapid increase of wireless subscribers increases the quality of services anytime, anywhere, and by any-media becoming indispensable. Integration of various networks such as CDMA2000 and wireless LAN into IP-based networks is required in these kinds of services, which further requires a seamless vertical handoff to 4^{th} generation wireless networks.

The proposed handoff algorithm between WLAN and CDMA2000 cellular network is implemented. The results of the simulation shows the behavior of the handoff and the time spent in WLAN or CDMA. The number of weak signal beacons determines whether a handoff is required or not. In this algorithm, traffic is classified into real-time and non real-time services.

INDEX WORDS: CDMA2000, WLAN, Handoff, Real-time, Non real-time, Throughput

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List of Abbreviations

AP – Access Point

BS – Base Station

CMR – Call-to-Mobility Ratio

CDMA – Code Division Multiple Access

EDGE – Enhanced Data rates for Global Evolution

FDMA – Frequency Division Multiple Access

GSM – Global System for Mobile

GSM – Global System for Mobile Communication

GPRS – Global Packet Radio Service

HO - Handoff

IP- Internet Protocol

LAN – Local Area Network

LA – Location Area

LCMR – Local Call-to-Mobility Ratio

LRU – Least Recently Used

MH – Mobile Host

MA – Mobile Agent

MD – Mobile Download

MU – Mobile Upward

MT – Mobile Through

MSL – Media Selection Layer

PDA – Personal Digital Assistant

PAN – Personal Area Networking

PDC – Personal Digital Cellular

PSTN – Public Switched Telephone Network

QoS – Quality of Service

RF – Radio Frequency

RAN – Radio Access Networking

SDOs – Standards Development Organizations

SDR – Software Defined Radio

SS7 – Signaling System 7

SA – Subnet Agent

SAc – Subnet Agent

SMS – Short Message Service

TDMA – Time Division Multiple Access

TDMA – Time Division Multiple Access

UMTS – Universal Mobile Telecommunications System

WCDMA – Wideband Code Division Multiple Access

3G – Third Generation

3GPP – Third Generation Partnership Project

1. Introduction

“The wireless telegraph is not difficult to understand. The ordinary telegraph is like a long cat. You pull the tail in New York, and it meows in Los Angeles. The wireless is the same, only without the cat.”-Albert Einstein

In the past decade, the telecommunications industry has witnessed an ever accelerated growth of the usage of the mobile communications. As a result, the mobile communications technology has evolved from the so-called second-generation (2G) technologies, GSM in Europe, IS-95(CDMA) and IS-136 (TDMA) in USA, to the third generation (3G) technologies. Along with the standards development for providing voice service to mobile users, a group of standards to deliver data to the mobile users have evolved from both SDOs (Standards development organisations) and industry. Systems and applications, such as Short Message Service (SMS) for sending and receiving short text messages for mobile phone users, have been built and continue to be developed.

The genius of the cellular system is the division of a city into small cells. This allows extensive frequency reuse across a city, so that millions of people can use cell phones simultaneously. In a typical analog cell-phone system in the United States, the cell-phone carrier receives about 800 frequencies to use across the city. The carrier divides the entire city into cells. Each cell is typically sized at about 10 square miles (26 square kilometers). Cells are normally thought of as hexagons on a larger hexagonal grid, as shown in Figure1.1:

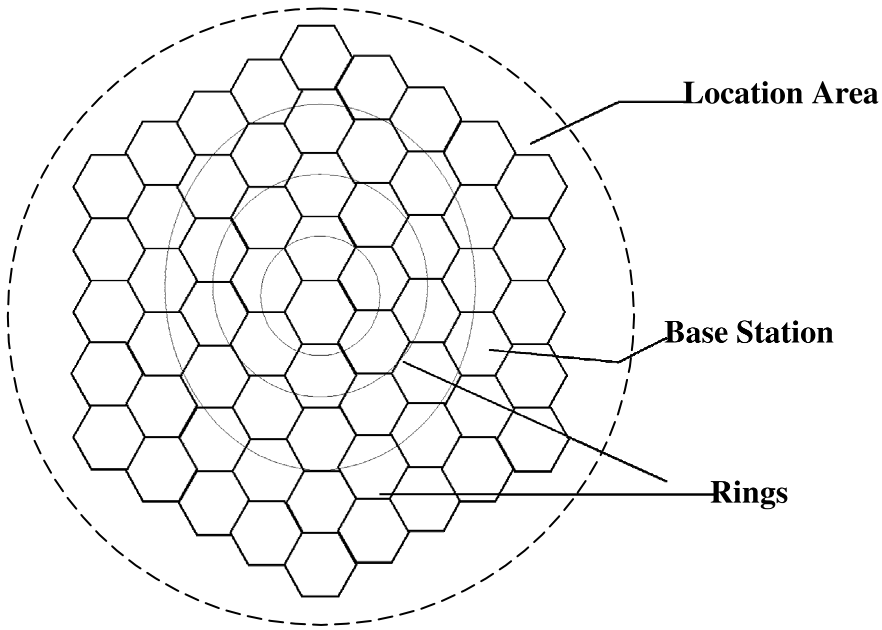

Figure 1.1 The Cell Topology

Each cell has a base station that consists of a tower and a small building containing the radio equipment that is used to communicate with Mobile Terminals over preassigned radio frequencies.

Cell phones have low-power transmitters in them. Many cell phones have two signal strengths: 0.6 watts and 3 watts [1]. The base station also transmits at low power. Low-power transmitters have two advantages:

- The transmissions of a base station and the phones within its cell do not make it very far outside that cell. Therefore, in Figure1.1, both of the cells in alternate rings and non-adjacent cells can reuse the same frequency. The same frequencies can be reused extensively across the city.
- The power consumption of a cell phone, which is normally battery-operated, is relatively low. Low power corresponds to small batteries, and this is what has made

handheld cellular phones possible.

The cellular approach requires a large number of base stations in a city of any size. A typical large city can have hundreds of towers. But because so many people are using cell phones, costs remain low per user. Each carrier in each city also runs one central office called the Mobile Telephone Switching Office (MTSO). This office handles all of the phone connections to the normal land-based phone system, and controls all of the base stations in the region. Groups of several cells are connected to a Mobile Switching Center (MSC) through which the calls are then routed to the telephone networks. The area serviced by a MSC is called a Registration Area (RA) or Location Area (LA). A group of RA's composes a Service Area (SA). Each SA is serviced by a Home Location Register (HLR). A wireless network may include several SAs and thus several HLRs.

All cell phones have special codes associated with them. These codes are used to identify the phone, the phone's owner and the service provider. Electronic Serial Number (ESN) (a unique 32-bit number programmed into the phone when it is manufactured), Mobile Identification Number (MIN) (a 10-digit number derived from the owners phone's number), and a System Identification Code (SID) (a unique 5-digit number that is assigned to each carrier by the FCC-Federal Communications Commission (A U.S. government agency charged with the task of regulating all forms of interstate and international communication)) are a few of the standard cell phone codes employed. While the ESN is considered a permanent part of the phone, both the MIN and SID codes are programmed into the phone when one purchases a service plan and has the phone activated.

2G systems such as GSM, IS-95, and cdmaOne were designed to carry speech and low-bit rate data. 3G systems were designed to provide higher data rate services. During the evolution from 2G to 3G, a range of wireless systems, including GPRS, Bluetooth, WLAN and HiperLAN have been developed. All these systems were designed independently,targeting different service types, data rates, and users. As these systems all have their own merits and shortcomings, there is no single system that is good enough to replace all the other technologies. In cellular networks such as GSM, a call is seamlessly handed over from one cell to another using hard handover without the loss of voice data. This is managed by networks based handover control mechanisms that detect when a user is in a handover zone between cells and redirect the voice data at the appropriate moment to the mobile node via the cell that the MN has just entered. In 4G networks a handover between different networks is required. A handover between different networks is referred to as a vertical handover. Although commercial mobile telephone networks existed as early as the 1940's, many consider the analog networks of the late 1970's to be the first generation (1G) wireless networks. The details of 1G, 2G, 3G and 4 G and their stages of evolution and the concepts involved are discussed in the Literature review of the Chapter 2. Features of 4G networks, possible architectures for 4G and various mobility management issues are discussed.

4G Networks are all IP based heterogeneous networks that allow users to use any system at anytime and anywhere. Users carrying any integrated terminal can use a wide range of applications provided by multiple wireless networks. 4G systems provide not only telecommunications services, but also a data-rate service when good system reliability is provided. 4G networks face number of challenges in providing service anywhere and anytime which are discussed in Chapter 3.

An event when a mobile station moves from one wireless cell to another is called Handoff. Handoff Criteria, Handoff Strategies, Handoff Methods, Handoff Scenarios and different types of handoffs are discussed in Chapter 4. WLAN-CDMA Cellular interconnection architecture based on IP [24] is discussed.

Chapter 5 discusses the Vertical handoff procedure and algorithm between WLAN and CDMA cellular network. Two different types of handoffs are discussed in this chapter. Mobile download handoff procedure in which mobile host moves from WLAN into CDMA network and Mobile Upward handoff procedure in which mobile host moves from CDMA into WLAN are discussed in detail. Chapter 6 discusses the simulation and code structure in detail.

In summary, this paper is organized as follows: Chapter 1 is the introduction. The literature review is provided in the second chapter. Features of 4G networks and challenges faced in deploying 4G networks are discussed in Chapter 3. Handoff in Networks is discussed in chapter 4. The details of the Vertical Handoff Procedure and algorithm between WLAN and CDMA are discussed in Chapter 5 with the details of the simulation model in Chapter 6. Chapter 7 draws the conclusion.

2. Literature Review

The History and evolution of mobile services from the 1G (first generation) to fourth generation are discussed in this section. Table1 presents a short history of mobile telephone technologies.

Technology	1G	2G	2.5	3G	4G
Design Began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2010
Service	Analog Voice, Synchronous data to 9.6 kbps	Digital Voice, short messages	Higher capacity, packetized data	Higher capacity, broadband data upto 2 Mbps	Higher capacity, completely IP-oriented, multimedia, data to hundreds of megabits
Standards	AMPS, TACS, NMT, etc	TDMA, CDMA, GSM, PDC	GPRS, EDGE, 1xRTT	WCDMA, CDMA2000	Single standard
Data Bandwidth	1.9 kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA,CDMA	CDMA	CDMA?
Core Network	PSTN	PSTN	PSTN, packet network	Packet network	Internet

Table 2.1 Short History of Mobile Telephone Technologies

First Generation	Second Generation	Third Generation	Fourth Generation
• Mobile Telephone Service: car phone	• Digital Voice + and Messaging -Data • Mobile Phone • Fixed Wireless Loop	• Integrated High Quality Audio, Video and Data. • Narrowband and Broadband Multimedia Services + IN/IP integration	• Dynamic information access • Telepresence (virtual meetings, education, and training) • Wearable devices
Analog Cellular Technology Macro cellular Systems	Digital Cellular Technology + IN emergence Microcellular and Pico cellular: Capacity, quality Enhanced Cordless Technology	Broader Bandwidth CDMA Radio Transmission Information Compression Higher Frequency Spectrum Utilization IN + Network Management integration ‰ IP technology	• Unified IP and seamless combination of • Broadband hot spots • WLAN/LAN/PAN • 2G/3G + 802.11 • Knowledge-Based Network Operations

Table 2.2 Wireless Network and Service Evolution

The history and evolution of mobile service from the 1G (first generation) to fourth generation process began with the designs in the 1970s that have become known as 1G. Refer to table 2.2 for an overview of the evolution of mobile service. The earliest systems were implemented based on analog technology and the basic cellular structure of mobile communication. These early systems solved many fundamental problems. The 2G systems designed in the 1980s were still used mainly for voice applications but were based on digital technology, including digital signal processing techniques. These 2G systems provided circuit-switched data communication services at a low speed.

During 1990s, two organizations worked to define next, or 3G, mobile system, which would eliminate previous incompatibilities and become a truly global system. The 3G system would have higher quality voice channels, as well as broadband data capabilities, up to 2Mbps. An interim step is being taken between 2G and 3G, the 2.5G. It is basically an enhancement of the two major 2G technologies to provide increased capacity on the 2G RF (Radio Frequency) channels and to introduce higher throughput for data service, up to 384 kbps. A very important aspect of 2.5G is that the data channels are optimized for packet data, which introduces access to the internet from mobile devices, whether telephone, PDA (Personal digital assistant), or laptop. However, the demand for higher access speed multimedia communication in today's society, which greatly depends on computer communication in digital format, seems unlimited.

Traditional phone networks (2G cellular networks) such as GSM, used mainly for voice transmission, are essentially circuit-switched. 2.5G networks, such as GPRS, are an extension of 2G networks, in that they use circuit switching for voice and packet switching for data transmission. Circuit switched technology requires that the user be billed by airtime rather than the amount of data transmitted since that bandwidth is reserved for the user. Packet switched technology utilizes bandwidth much more efficiently, allowing each user's packets to compete for available bandwidth, and billing users for the amount of data transmitted. Thus a move towards using packet-switched, and therefore IP networks, is natural.

3G networks were proposed to eliminate many problems faced by 2G and 2.5 G networks, like low speeds and incompatible technologies (TDMA/CDMA) in different countries. Expectations for 3G included increased bandwidth: 128Kbps in a car and 2 Mbps in fixed applications. In theory, 3G would work over North American as well as European and Asian wireless air interfaces. In reality, the outlook for 3G is neither clear nor certain. Part of the problem is that network providers in Europe and North America currently maintain separate standards' bodies. The standards' bodies mirror differences in air interface technologies. In addition there are financial questions as well that cast a doubt over 3G's desirability. There is a concern that in many countries, 3G will never be deployed. This concern is grounded, in part, in the growing attraction of 4G wireless technologies.

A 4G or 4^{th} generation network, a new generation of wireless is intended to complement and replace the 3G systems. Accessing information anywhere, anytime, with a seamless connection to a wide range of information and services, and receiving a large volume of information, data, pictures, video, and so on as shown is Figure 2.2 are the keys of the 4G infrastructures.

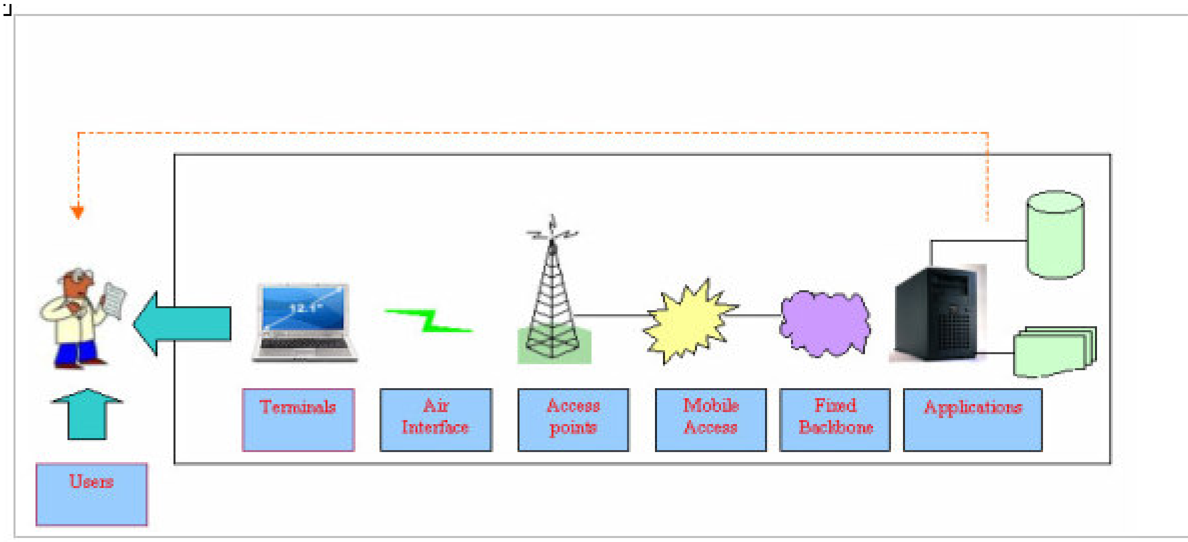

Figure 2.2 4G Visions [3]

The future 4G infrastructure [3] will consist of a set of various networks using IP as a common protocol so that users are in control because they will be able to choose every application and environment. A 4G or 4th generation network is the name given to an IP-based mobile system that provides access through a collection of radio interfaces. A 4G network promises seamless roaming/handover and best connected service, combining multiple radio access interfaces (such as WLAN, Bluetooth, GPRS) into a single network that subscribers may use [12]. With this feature, users will have access to different services, increased coverage, the convenience of a single device, one bill with reduced total access cost, and more reliable wireless access even with the failure or loss of one or more networks.

4G was simply an initiative by R & D labs to move beyond the limitations, and address the problems of 3G which was having trouble meeting its promised performance and throughput. In the most general level, 4G architecture includes three basic areas of connectivity: Personal Area Networking (such as Bluetooth), local high-speed access points on the network including wireless LAN technologies, and cellular connectivity. 4G calls for a wide range of mobile devices that support global roaming. Each device will be able to interact with Internet-based information that will be modified on the fly for the network being used by the device at that moment. The roots of 4G lie in the idea of pervasive computing [20]. The glue for all this is likely to be software defined radio (SDR) [13]. SDR enables devices such as cell phones, PDAs, PCs and a whole range of other devices to scan the airwaves for the best possible method of connectivity, at the best price. In an SDR environment, functions that are formerly carried out solely in hardware – such as the generation of the transmitted radio signal and the tuning of the received radio signal – are performed by software [7]. Thus, the radio is programmable and able to transmit and receive over a wide range of frequencies while emulating virtually any desired transmission format. As the number of wireless subscribers rapidly increases guaranteeing the quality of services anytime, anywhere, and by any-media becomes indispensable. These services require various networks to be integrated into IP-based networks, which further require a seamless vertical handoff to 4^{th} generation wireless networks. And as one of the next generation mobile communications, the 4^{th} generation mobile communications provides various services, such as high-speed data services and IP-based access to Radio Access Network, etc. Various interface techniques such as WLAN, Bluetooth, UTMS, and CDMA2000 are integrated into the IP-based networks as an overlay structure. In this structure, the optimum services are provided to mobile hosts. Mobile hosts in this structure can be connected to the network through various access points. Moreover, a seamless handoff should also be supported between different air interface techniques during inter-network movement.

2.1 Features of 4G Networks

High Speed - 4G systems should offer a peak speed of more than 100Mbits per second in stationary mode with an average of 20Mbits per second when travelling.

High Network Capacity – Should be at least 10 times that of 3G systems. This will quicken the download time of a 10-Mbyte file to one second on 4G, from 200 seconds on 3G, enabling high-definition video to stream to phones and create a virtual reality experience on high-resolution handset screens.

Fast/Seamless handover across multiple networks – 4G wireless networks should support global roaming across multiple wireless and mobile networks.

Next-generation multimedia support – The underlying network for 4G must be able to support fast speed volume data transmission at a lower cost than today.

The goal of 4G [4] is to replace the current proliferation of core mobile networks with a single worldwide core network standard, based on IP for control, video, packet data, and voice. This will provide uniform video, voice, and data services to the mobile host, based entirely in IP. The objective is to offer seamless multimedia services to users accessing an all IP based infrastructure through heterogeneous access technologies. IP is assumed to act as an adhesive for providing global connectivity and mobility among networks. An all IP-based 4G wireless network has inherent advantages over its predecessors. It is compatible with, and independent of the underlying radio access technology [4].

An IP wireless network replaces the old Signalling System 7 (SS7) [6] telecommunications protocol, which is considered massively redundant. This is because SS7 signal transmission consumes a larger part of network bandwidth even when there is no signalling traffic for the simple reason that it uses a call setup mechanism to reserve bandwidth, rather time/frequency slots in the radio waves. IP networks, on the other hand, are connectionless and use the slots only when they have data to send. Hence there is optimum usage of the available bandwidth. Today, wireless communications are heavily biased toward voice, even though studies indicate that growth in wireless data traffic is rising exponentially relative to demand for voice traffic. Because an all IP core layer is easily scalable, it is ideally suited to meet this challenge. The goal was a merged data/voice/multimedia network.

2.2 Possible Architectures for 4G Networks

Accessing different mobile and wireless networks is one of the most challenging problems to be faced in the deployment of 4G technology [22]. Figure 2.3 shows three possible architectures:

- Using a multimode device
- An overlay network
- A common access protocol

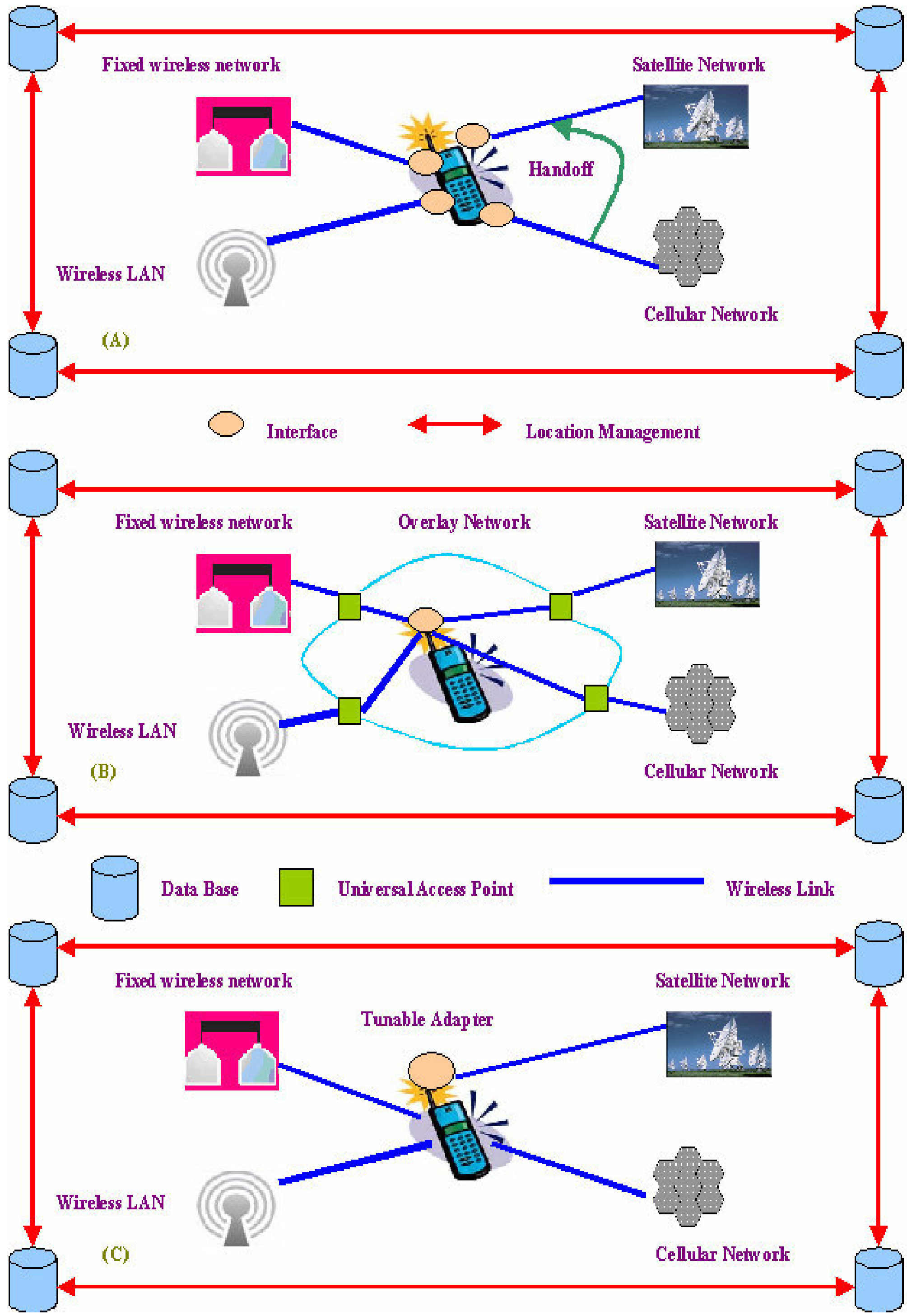

Figure 2.3 Possible Architectures for 4G Networks [22]

2.2.1 Multimode Devices

To access services on different wireless networks, one single physical terminal with multiple interfaces is used. Existing advanced mobile phone system on code division multiple access dual function cell phone, dual function satellite cell phone and global system for mobile telecommunications are examples of Multimode Device architecture. Call completion can be improved and coverage area is expanded effectively using this architecture. When there is network, link or switch failure, reliable wireless coverage should be provided. The handoff between networks can be initiated by user, device or network. There is no requirement of wireless network modification or employment of interworking devices as the device itself incorporates most of the additional complexity. A database can be deployed by each network which stores the information to keep track of user location, device capabilities, network conditions and user preferences.

2.2.2 Overlay Network

There are several universal access points in overlay network with which a user can access. A wireless network is selected by each universal access points based on availability, quality of service specifications and user defined choices [8]. Protocol and frequency translation, content adaptation is performed by universal access point on behalf of users. As the user moves from one universal access point to another, rather than the user or the device, handoffs are performed by overlay networks. User, network, device information, capabilities and preferences are stored by the universal access point. Single billing and subscription is supported as universal access points keep track of the various resources a caller uses.

2.2.3 Common Access Protocol

Supporting one or two standard access protocols by wireless networks allows this protocol to become viable. Using wireless asynchronous mode requires interworking between different networks as one possible solution. Transmission of ATM cells with additional headers or wireless ATM cells requiring changes in the wireless networks must be allowed by every wireless network to implement wireless ATM. One protocol might be used by one or more types of satellite based networks while another protocol is used by one or more terrestrial wireless networks.

2.3 Mobility Management Issues in 4G Networks

A critical aspect of 4G is Mobility [2]. The three main issues regarding mobility management [16] in 4G networks are as follows:

1) The optimal choice of access technology or how to be best connected is the first issue dealt with in the mobility of 4G. Considering how the terminal and an overlay network choose the radio access technology is necessary when a user is given connectivity from more than one technology at any one time.

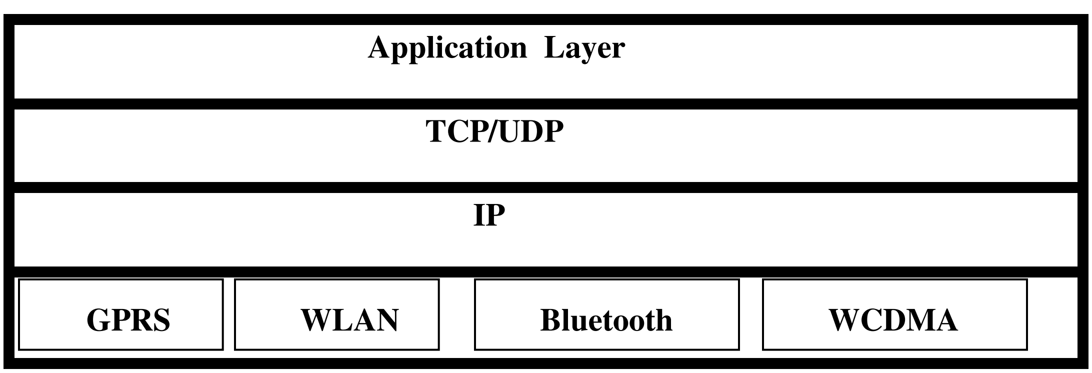

Figure 2.4 Network Technologies

There are several network technologies available today, which can be viewed as complementary. For high data rate indoor coverage, WLAN is best suited. GPRS or UMTS are best suited for nation wide coverage and can be regarded as wide area networks, providing a higher degree of mobility. An optimal choice of radio access technology among all those available should be made by the user of the mobile terminal or the network. The network to be connected and when to perform a handover between different networks are determined by a handover algorithm. Ideally, the handover algorithm would assure that the best overall wireless link is chosen. The type of application being run by the user at the time of handover should be taken into consideration during the network selection strategy. This ensures stability as well as optimal bandwidth for interactive and background services.

2) The second issue regards the design of a mobility enabled IP networking architecture, which contains the functionality to deal with mobility between access technologies.This includes fast, seamless vertical (between heterogeneous technologies) handovers (IP micro-mobility), quality of service (QoS), security and accounting. Real-time applications in the future will require fast/seamless handovers for smooth operation. Mobility in IPv6 [15] is not optimised to take advantage of specific mechanisms that may be deployed in different administrative domains. Instead, IPv6 provides mobility in a manner that resembles only simple portability. To enhance mobility in IPv6, 'micro-mobility' protocols, Cellular IP and Hierarchical Mobile IPv6 [5] have been developed for seamless handovers i.e.; handover that result minimal handover delay, minimal packet loss, and minimal loss of communication state.

3) The adaptation of multimedia transmission across 4G networks is the third and the last issue. As multimedia is the main service feature of 4G networks, and changing radio access networks may in particular result in drastic changes in the network changes. Thus the

framework for multimedia transmission must be adaptive. In cellular networks such as UMTS, users compete for scarce and expensive bandwidth. Variable bit rate services provide a way to ensure service provisioning at lower costs. In addition the radio environment has dynamics that renders it difficult to provide a guaranteed network service. This required that the services are adaptive and robust against varying radio conditions. High variations in the network Quality of Service [18] leads to significant variations of the multimedia quality. The result could sometimes be unacceptable to the users. Avoiding this requires choosing an adaptive encoding framework for multimedia transmission. The network should signal QoS variations to allow the application to be aware in real time of the network conditions. User interactions will help to ensure personalised adaptation of the multimedia presentation.

Wireless Mobile Networks has Mobility Management as an integral function. Mobility Management influences the type and quality of Wireless Network service offerings. Each generation of Wireless Mobile Network has different mechanisms for Mobility Management. Network support of subscriber mobility requires registration, authentication, paging, roaming, radio resource management and excess channel capacity. Mobility Management focuses on the network’s ability to allocate radio access network resources.

3. Challenges in 4G Networks

4G Networks are all IP based heterogeneous networks that allow users to use any system at anytime and anywhere. Users carrying any integrated terminal can use a wide range of applications provided by multiple wireless networks. 4G systems provide not only telecommunications services, but also a data-rate service when good system reliability is provided. At the same time, a low per-bit transmission cost is maintained. Users can use multiple services from any provider at the same time. Imagine a 4G mobile user who is looking for information on movies shown in nearby cinemas. The mobile may simultaneously connect to different wireless systems. These wireless systems may include Global Positioning System (GPS) (for tracking users current location), a wireless LAN (for receiving previews of the movies in nearby cinemas), and a code-division multiple access (for making a telephone call to one of the cinemas). In this example, the user is actually using multiple wireless services that differ in quality of service (QoS) levels [18], security policies, device settings, charging methods, and applications. There are number of challenges faced by 4G networks in integrating all the services.

3.1 An overview of challenges in Integrating Heterogeneous Systems

The challenges mentioned in the above table are grouped into three different aspects:

- Mobile Station
- System
- Service

3.1.1 Mobile Station

To use large variety of services and wireless networks in 4G systems, multimode user terminals are essential as they can adapt to different wireless networks by reconFigureuring themselves. The need to use multiple terminals is eliminated. Adapting software radio approach is the most promising way of implementing multimode user terminals [14]. The analog part of the receiver consists of an antenna, a bandpass filter, and a low noise amplifier. The received analog signal is digitized by the analog/digital converter immediately after the analog processing. The processing in the next stage is then performed by a reprogrammable baseband digital signal processor. The digital signal processor will process the digitized signal in accordance with the wireless environment. Unfortunately, the current software radio technology is not completely feasible for all the different wireless networks due to the following technological problems. It is impossible to have one antenna and one low noise amplifier to serve the wide range of frequency bands. Using multiple analog parts to work in different frequency bands is the only solution. The design complexity and physical size of a terminal are increased. And existing analog/digital converters are not fast enough.

3.1.2 System

For 4G infrastructure to provide wireless services at any time and anywhere, terminal mobility is a must. Terminal mobility allows mobile clients to roam across geographic boundaries of wireless networks. The two main issues in terminal mobility are location management and handoff management. The system tracks and locates a mobile terminal for possible connection. Location management involves handling all the information about the roaming terminals, such as original and current located cells, authentication information, and

QoS capabilities. Handoff Management maintains ongoing communication when the terminal roams. Mobile IPv6 is a standardized IP-based mobility protocol for IPv6 wireless systems. Each terminal has an IPv6 home address. Whenever the terminal moves outside the local network, the home address becomes invalid, and the terminal obtains a new IPv6 address called care-of address in the visited network. A binding between the terminal's home address and care-of address is updated to its home agent in order to support continuous communications. This kind of handoff process causes an increase in system load, high handover latency, and packet losses. It is hard to decide the correct handoff time because measuring handoffs among different wireless systems is very complicated. The uncertain handoff completion time adds to the complexity in designing good handoff mechanisms.

3.1.3 Services

More comprehensive billing and accounting systems are needed, with the increase of service varieties in 4G systems. Customers may subscribe to many services from a number of service providers at the same time rather than only one operator. Dealing with multiple service providers might be inconvenient for customers. Operators need to design new business architecture, accounting processes, and accounting data maintenance. It is challenging to formulate one single billing method that covers all the billing schemes involved. 4G networks support multimedia communications, which consists of different media components with possibly different charging units. This adds difficulty to the task of designing a good charging scheme for all customers. The media components may have different QoS requirements. To decide a good tariff for all possible components is very complicated. To build a structural billing system for 4G, several frameworks have been studied [21].

4. Handoff in Networks

The services provided by the public switched telephone networks (PSTN) [23] are leveraged by wireless mobile telephone network of public land mobile networks (PLMN). PSTNs ate backbones to PLMNs. Infrastructure for wireless access, mobility management and external network gateways are provided by the network elements of PLMNs.

A simple PLMN [23] consists of the following components:

- Base stations
- Mobile switching service centres (MSC)
- Home Location Register (HLR)
- Visitor Location Registers (VLR)
- Authentication Centre (AUC)
- Equipment Identification Register (EIR).

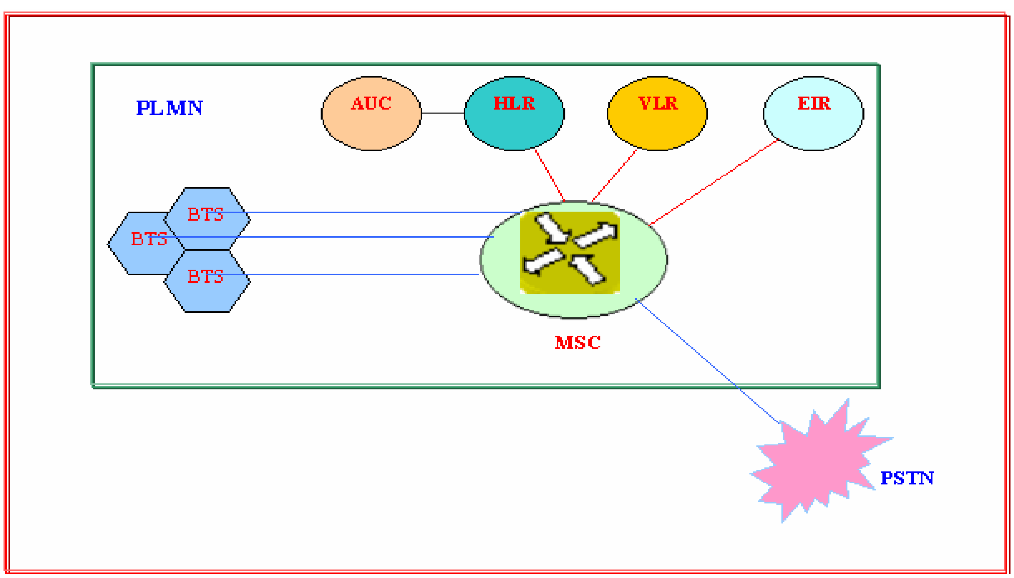

Figure 4.1 Simple PLMN [23]

Radio interface for mobile subscribers are used to provide network access by the base stations. Managing base stations, consulting PLMN database to establish subscriber access rights, routing mobile traffic is managed by MSC. MSC also serves as a gateway to external networks. Subscriber profiles, location encryption codes and equipment data are stored in PLMN databases. HLR, VLR, AVC and EIR are PLMN databases.

All telephone networks require fundamental services like Call establishment and connection maintenance. Call initiation signalling, connection path establishment, alerting called party, call acceptance and preservation of connection until end of session signalling is detected consists of the PSTN call process for two authorized fixed location subscribers. The PSTN uses the fixed location of the subscriber to simplify network functions. Authentication, call establishment and call preservation are simplified by fixed subscriber location. Subscriber mobility significantly complicates network operations, although a PLMN call process performs the same functions of a PSTN.

PLMNs must implement mobility management technologies to provide PSTN services. These technologies enable PLMNs to establish and maintain calls to authorized mobile subscriber. Mobility Management uses the HLR, VLRs, MSCs and Base Stations. Call quality, reliability and availability are strongly influenced by Mobility Management technologies. Mobility Management is the ability of a PLMN to orchestrate calls for its subscribers and radio management maintains the call regardless of the mobility of the subscribers. PLMNs must track and dynamically route calls to its subscribers in a transparent fashion. The main functions of mobility management are locating, authenticating and tracking mobile subscribers. PLMNs use a registration process to report a mobile station's right to access network services. Roaming allows authorized mobile subscribers to use networks other than their home PLMN. Signal quality assessments, base station selection and switching constitute Radio Resource Management (RRM).

4.1 Handoff Criteria

Increasing distance from the base station attenuates the radio signal as a subscriber travels away from its base station.

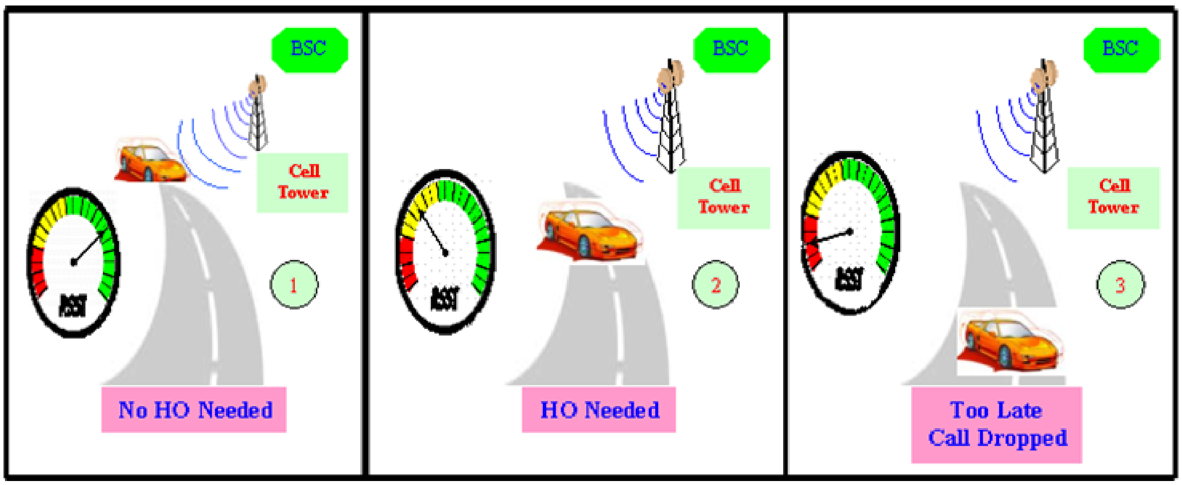

Figure 4.2 Signal Quality Behaviors [23]

Prior to loss of communication, reliable detection of this condition is crucial. When deteriorating signal strength is detected the PLMN responds by seeking an alternative base station with higher signal strength. The PLMN moves the call to the new base station and releases the previous base station after selecting and reserving a new base station channel.

Received signal strength is described by Received Signal Strength Indicator (RSSI) and handoff process relies on this signal strength. As the characteristics of base station and mobile handset receivers are well known, it is possible to predict performance ranges based on received signal levels. The crucial factor for PLMN's radio resource management is accurate and reliable signal quality assessments between the mobile station and its serving base station. Real time measurements effect PLMN's rapid execution of handoffs. Another key parameter for radio resource management is the reference point of signal strength measurements. The PLMN can use measurements made at the base station, handset or both as a reference for resource switching decisions.

4.2 Handoff Strategies

An event when a mobile station moves from one wireless cell to another is called Handoff. Handoff can be of two types: horizontal (intra-system) and vertical (inter-system) cases. Handoff within the same wireless access network technology is considered as Horizontal handoff, and handoff among heterogeneous wireless access network technologies is considered vertical handoff. The terminology of horizontal and vertical reflects the wireless access network technology instead of the administrative domain in comparison to macro- and micro mobility. There are different subclasses such as follows:

- Vertical macro mobility refers to mobility among different administrative domains using different wireless technologies
- Horizontal macro mobility refers to mobility among different administrative domains using the same wireless technology
- Vertical micro mobility refers to mobility within the same administrative domain using different wireless technologies
- Horizontal micro mobility refers to mobility within the same administrative domain using the same wireless technology.

4.3 Handoff Methods

Handoffs have several methods and they are technology dependent. The two main handoff methods are:

- Hard Handoff: It has a brief disruption of service as it has to break before a making a switching action. Hard Handoffs are used by Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) systems.

- Soft Handoff: It has no disruption of service action as it makes a switching action before the break. Multiple network resources are used by soft handoffs. Soft handoffs are used by CDMA system.

Figure 4.3 shows two different handoffs.

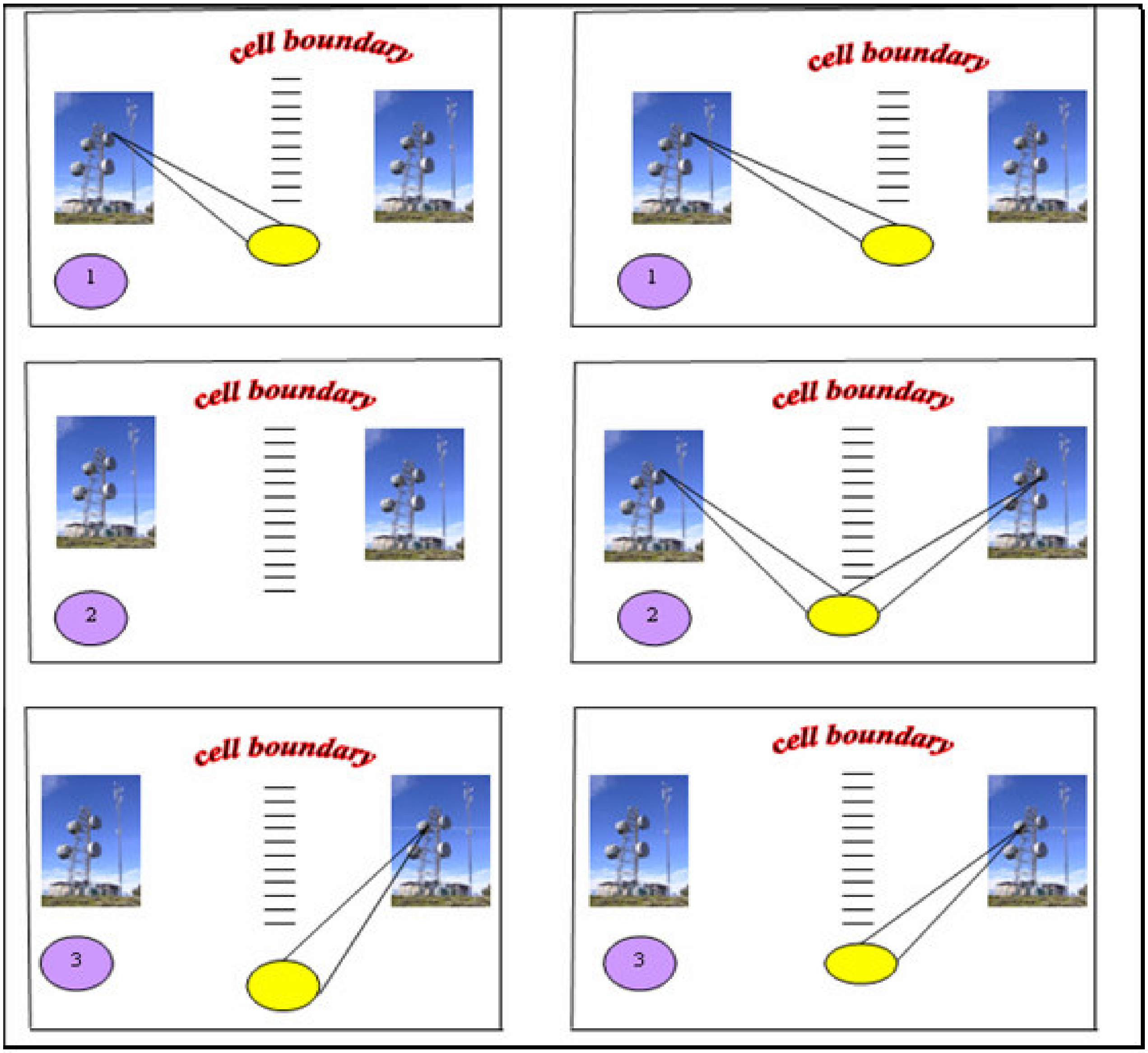

Figure 4.3 Handoff Methods [23]

4.4 Handoff Scenarios

As mobiles traverse cell or sector boundaries, majority of handoffs support calls. The following are scenarios where Handoff processes are required:

- Intra-MSC - Involve crossing cell boundaries within a MSC's service area
- Inter-MSC - Involves crossing cell boundaries between MSCs

- Roaming - Involves crossing cell boundaries between different network operators
- Intra-cell – Involves crossing sector boundaries within a cell
- Switching channels to circumvent persistent interference

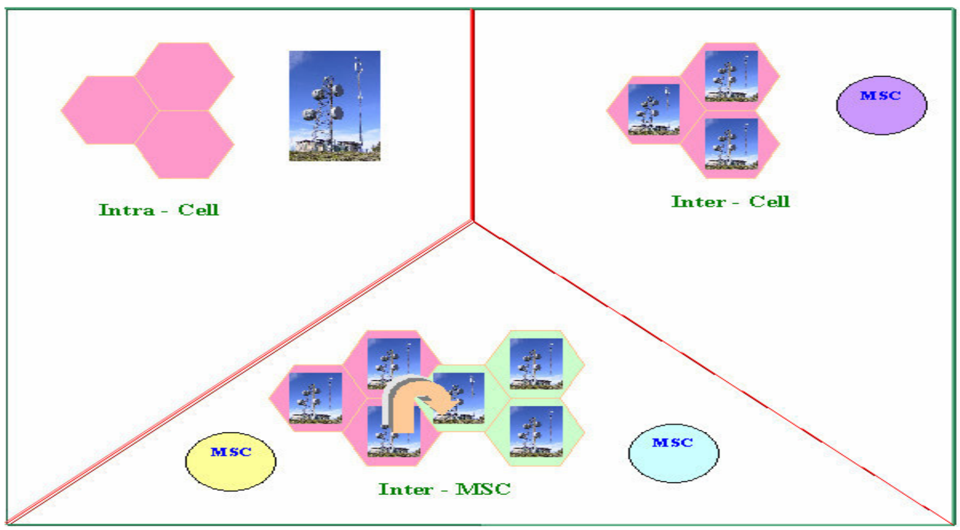

Figure 4.4 Basic Handoff Scenarios [23]

4.5 Horizontal Handoff

A Horizontal handoff is a handoff between two network access points that use the same network technology and interface. For example, when a mobile device moves in and out of various 802.11b network domains, the handoff activities would be considered as a horizontal handoff, since connection is disrupted solely by device mobility.

4.6 Vertical Handoff

A Vertical handoff is a handoff between two network access points, which are using different connection technologies. For example, when mobile device moves out an 802.11b network into a GPRS network, the handoff would be considered a vertical handoff.

4.7 Support for Vertical Handoffs

The current IPv6 [17] specification does not support vertical handoffs. Since IP is the common protocol, everything below it is abstracted from the application. For the application, it is always connected as handoffs occur. To provide this support in IPv6 a daemon can be run at the network layer which takes care of switching between different radio accesses technologies. The mobile device might be having separate interface cards for each of the networks or may use a single multimode card which works in different modes at different times. The protocol stacks of each of the different radio access technology are stored in the mobile device. The daemon in the network layer will then choose which radio access network (RAN) to use on the basis of network speed, quality of service, cost of usage and other similar criteria. The selection policies are customizable and changes between different RANs are automatic and transparent to the user and depend on coverage and network load conditions. After selecting the RAN, the daemon then initializes the appropriate protocol stack before starting to use that interface. This way the IP datagrams being passed down get encapsulated in the correct format of the radio access technology in use. This model allows the device to utilize any interface as long as the hardware is present by just installing the necessary stack protocols.

A seamless handoff should also be supported between different air interface techniques during inter-network movement. This type of handoff is called a vertical handoff, because the mobile is moving to another network (heterogeneous network) which has a different air interface technique. Various wireless LAN services are being introduced in hotspot areas such as campuses, hotels and offices. IEEE802.11 WLAN services having high bandwidth are used to cover limited hotspot areas. If the mobile host (MH) goes out of the hotspot coverage, the call will be dropped. In the 4th generation, a WLAN cell is overlaid within a CDMA2000 cell that is constructed into an ALL-IP based network. A seamless handoff is supplied through the vertical handoff process even if the MH goes out of the WLAN coverage area. The minimised cell size in 4th generation networks results in frequent handoffs.

Recently proposed network architecture and procedure for the vertical handoff [24] adopts the mobility management concept through the Mobile Agent (MA) and Subnet Agent (SA) functions to minimize the delay during vertical handoff. The first goal of seamless handoff is low handoff latency, power saving, and low bandwidth overhead [8]. WLAN and CDMA 2000 networks have different frequency, maximum data speed and cost characteristics. The time for the handoff procedure to begin in the handoff region is decided by the handoff delay time and throughput according to traffic characteristics. The real-time traffic preferentially takes into account the handoff delay, and the non-real time traffic takes the throughput into account.

Methods for interconnecting CDMA2000 networks with heterogeneous air interfaces and WLAN use emulators, virtual access points, or mobile IP. Mobile IP [9] method is operated peer-to-peer relationship that shows better performance than the previous two methods that operate in master/slave relationship. An IP-based architecture using mobile IP is shown in Figure 4.5

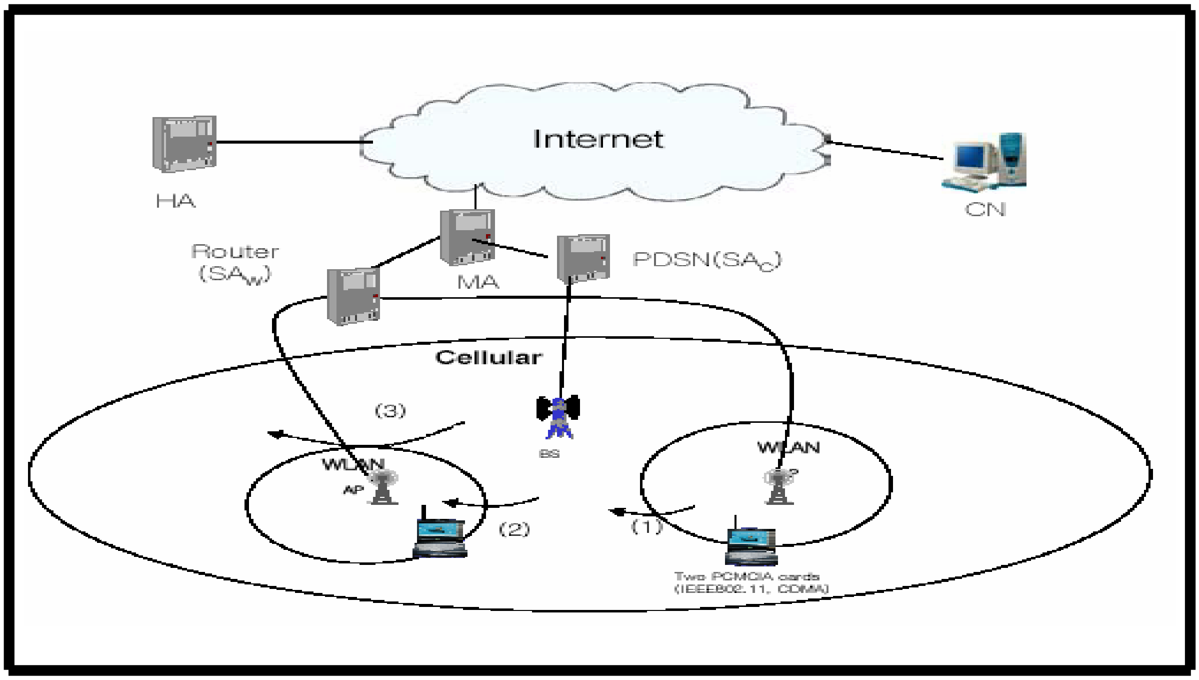

Figure 4.5 WLAN-CDMA Cellular Interconnection Architecture based on IP [24]

In the WLAN-CDMA Cellular Interconnection architecture [24], handoff occurs in the following cases:

- Mobile Download
- Mobile Upward
- Mobile Through

Mobile Download

When the mobile host serviced in the WLAN region moves to another area and is synchronized to the CDMA network Mobile Download occurs.

Mobile Upward

When the Mobile Host enters into a WLAN from the cellular network outside the WLAN, mobile upward occurs.

Mobile Through

When one of the two networks in the media selection layer is selected, Mobile Through occurs.

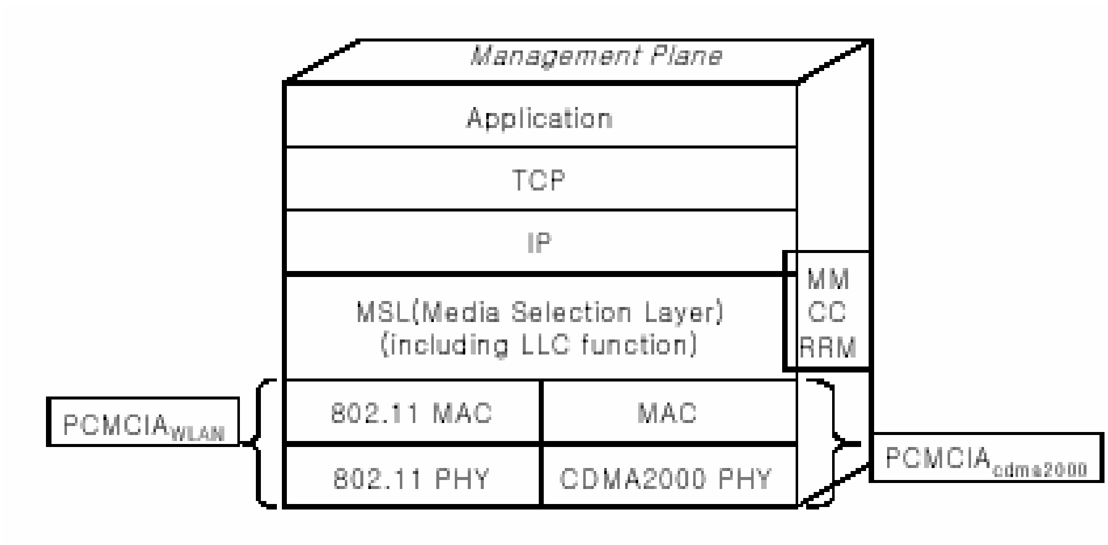

Figure 4.6 Mobile Host Protocol STACK [24]

The mobile host saves power by operating only one interface card when operating in the handoff transition region before it goes into the handoff transition region. The mobile host after moving into the transition region then activates the interface card for the neighbors.

5. Vertical Handoff Procedure and Algorithm between IEEE802.11 WLAN and CDMA cellular network

A seamless vertical handoff procedure [24] between IEEE802.11 WLAN and CDMA2000 cellular network that overlays the WLAN and also covers a larger area is discussed in this chapter. The traffic is classified into real-time and non real-time services in this algorithm. The architecture adopts the mobility management concept through the Mobile Agent and the Subnet Agent functions to minimize the delay during vertical handoff. MD Handoff involves the process in which mobile host leaves the WLAN service area and connects to the CDMA cellular network. The strength of the beacon signal weakens as the Mobile Host moves away from the WLAN access point. The signal strength is compared with the threshold value and if the signal strength value goes below the threshold value, then the CDMA Cellular card is activated and the MH moves into the CDMA from WLAN resulting in the handoff.

When an Agent Advertisement message is received from the Cellular subnet agent, the MH sends a Handoff Ready Request message to the MA through the required access point. A subnet agent of the cellular network is configured with the overlay network that buffers the received packets. The MA sends incoming packets to the subnet agent. The subnet agent in turn receives a Registration message and will start sending the buffered packets. Buffering is done in order to save the in bound packets during the handoff period.

The handoff algorithm is executed when the beacon signals are below the threshold value. A Route Update message is sent by the MA after the handoff to the base station to request traffic channel allocation [19]. Registration to the SA and MA is performed. As soon as the MH registers to the SA, the buffered packets in the SA are sent to the base station. The disassociation message is sent to the access point. CDMA cellular network is communicated by the MA.

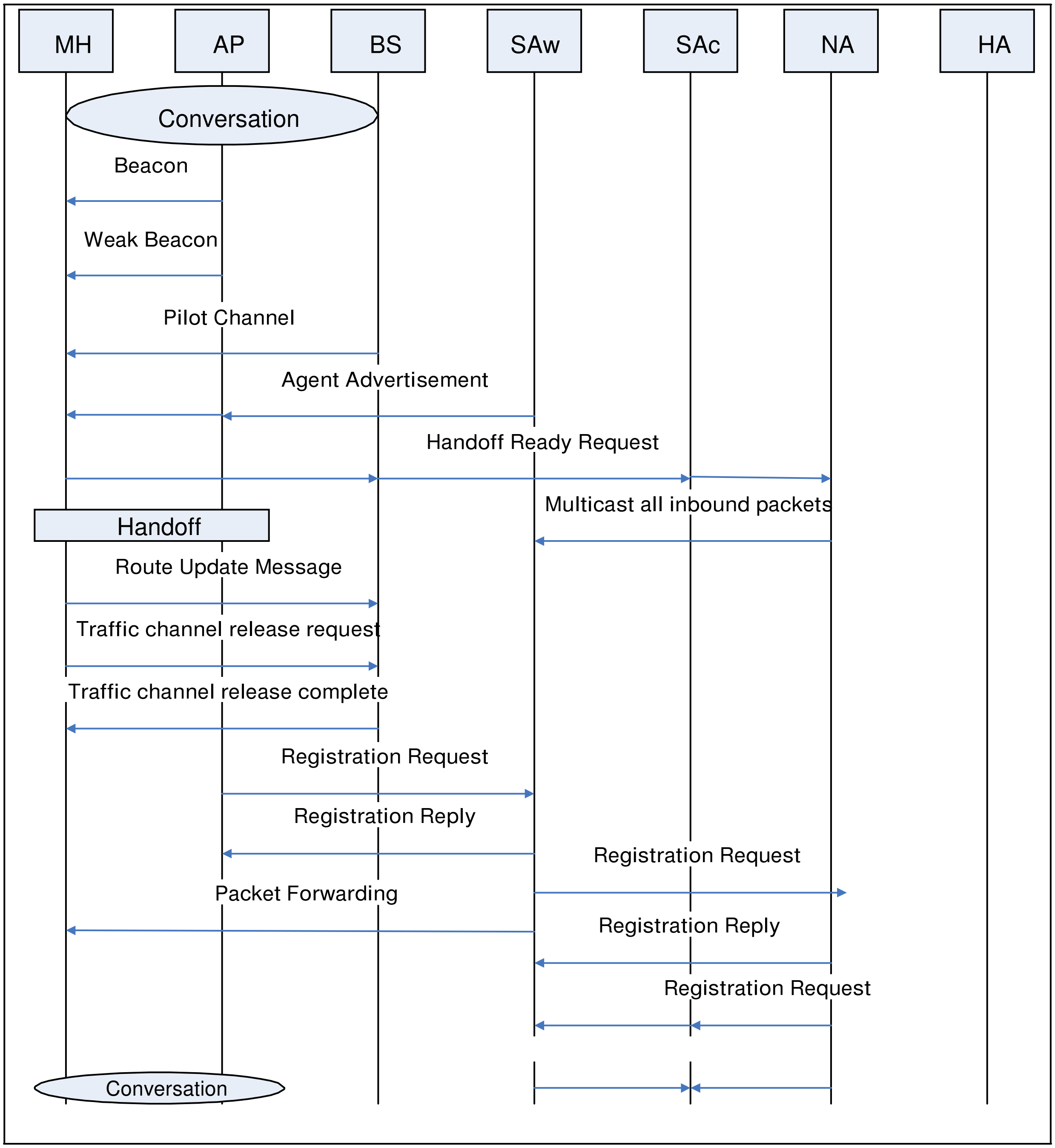

Figure 5.1 MD Handoff Signaling Flow

When the MH serving in the CDMA cellular network region enters the WLAN service region, it connects to the WLAN. This is called the MU handoff. The Figure 5.2 shows the signalling flow:

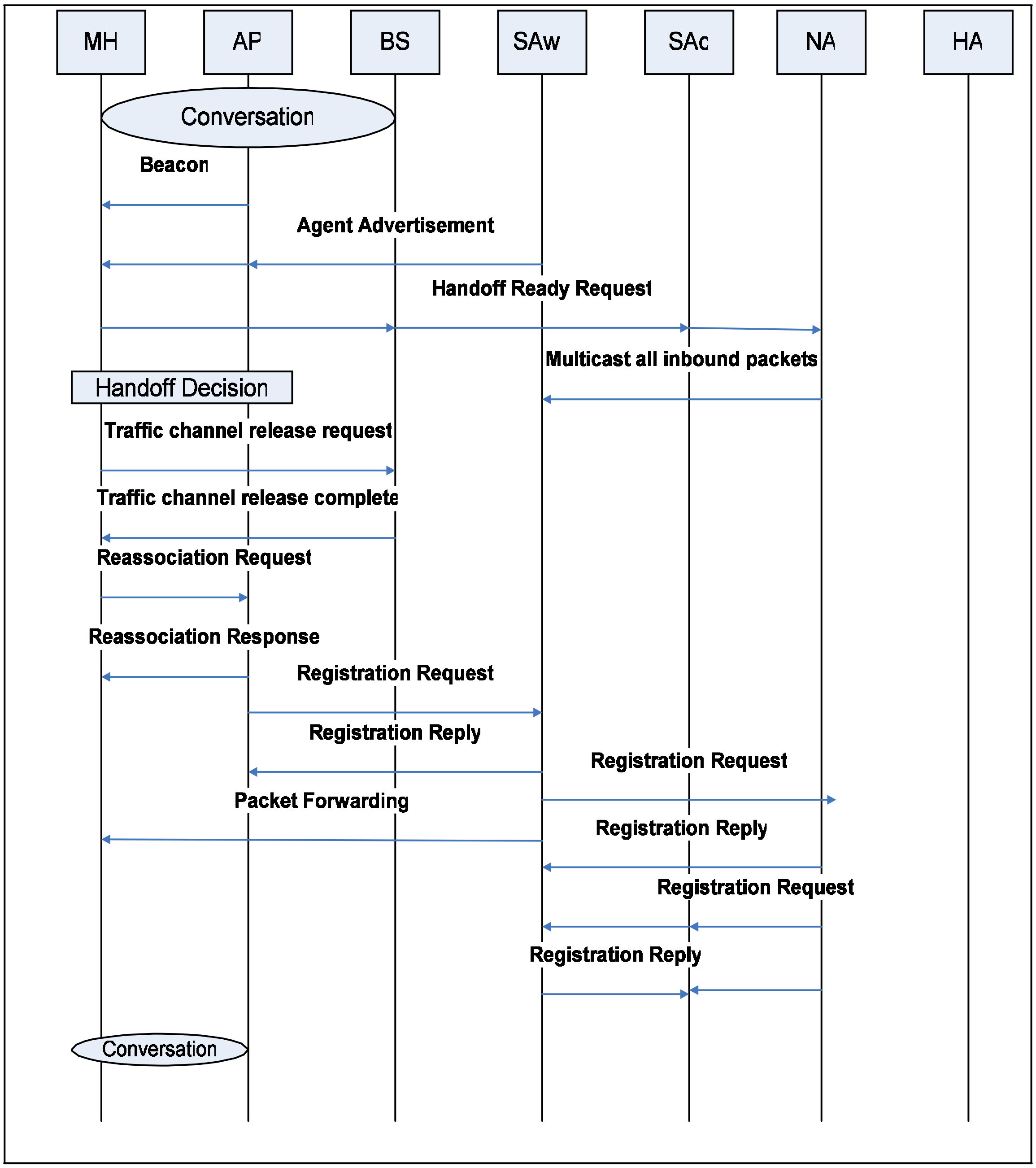

Figure 5.2 MU Handoff Signaling flow

Power saving can be achieved in this case by determining the time of the checking beacon signal in the handoff transition region, and the time to activate the WLAN card in the MH. For example, position information can be used. For the seamless handoff service, the handoff point in the MU is not a critical factor, because the cellular network covers the WLAN region with an overlay network.

In the Figure5.2, the MH receives a beacon signal from the AP through activating the WLAN card. If the MH receives an Agent Advertisement message from the SA, it sends a Handoff Ready Request message to the MA through the currently serving cellular network. Then the MA transmits in-bound packets to the SA of the WLAN. After that, the MH checks the received beacon signals continuously to determine whether to handoff or not. If the conditions for the handoff are satisfied, then the handoff procedure is performed. The MH requests the release of the channel that is allocated to the CDMA cellular network and transmits a Reassociation Request message to the AP in the WLAN. From now on, the MH communicates with the WLAN network.

5.1 Handoff Algorithm and Analysis

There are many differences between the radio link characteristics of the WLAN and the CDMA Cellular networks. Hot spot areas, such as campuses, hotels, and restaurants are covered by WLAN at low cost and high data rate. However, CDMA cellular networks serve a wider area than WLAN at a higher cost and lower data rate. The following tables show the coverage, cost and data rate of WLAN and CDMA.

RA	Coverage	Data Rate	Cost
AP	Limited	1 – 11 Mbps	Low
BSS	Unlimited	9.6 – 300 Kbps	High

Table 5.1 Specifications of AP and BSS

	Conversational Class	Streaming Class	Interactive Class	Background Class
BER	10^{-3}	10^{-5}	10^{-8}	10^{-9}
Delay	Strict and low	Bounded	Tolerable	Unbounded
Guaranteed Rate	Yes	Yes	No	No
Application	Voice, Internet Game	VOD,Cable TV	Web, Telnet	FTP, E-mail

Table 5.2 Application Traffics

Depending on the delay sensitivity characteristics application traffics [10] are further classified into two groups. Conversation and streaming classes that are sensitive to delay are classified as real-time services. The loads in both the networks are assumed to be nominal. In such case, there is a tradeoff between the handoff delay and throughput during those handoff operations, which occur between networks whose radio links have different characteristics.

In the case of delay sensitive real-time services, handoff should be performed as rapid as possible in order to minimize the delay due to frequent handoffs. For non real-time service, the amount of transmission data is more important than the delay, and therefore, the connection to the WLAN should be maintained as long as possible. The proposed Vertical handoff algorithm between WLAN and CDMA cellular networks is shown in Figure5.3: [24]

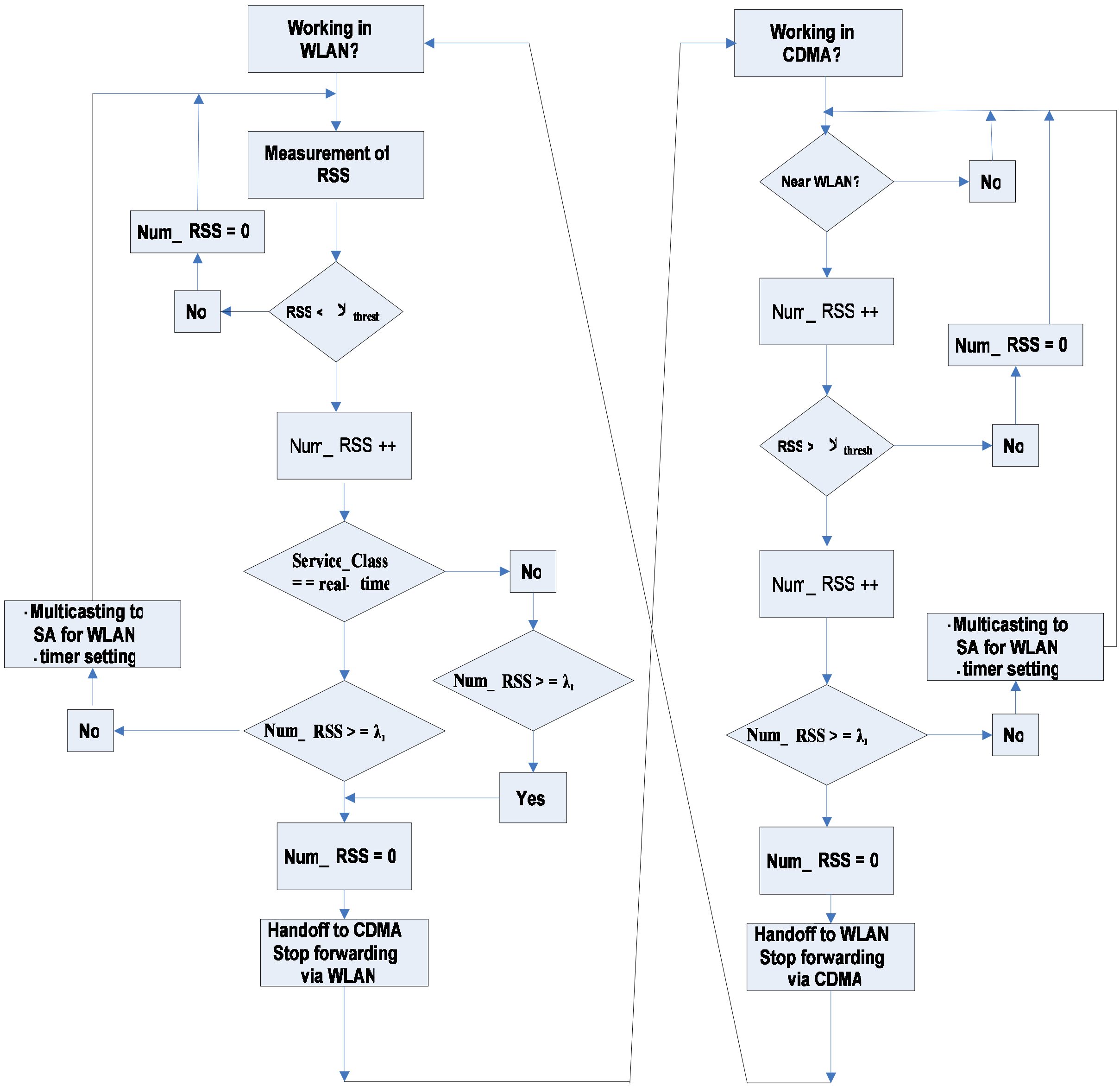

Figure 5.3 Handoff algorithm between WLAN and CDMA [24]

The following variables are used to determine the vertical handoff [11]:

λ_{thresh} : Predefined threshold value when the handoff transition region begins

λ : The number of continuous beacon signals that are received from the WLAN with the below λ_{thresh}

λ_r : λ for real time service

λ_u : λ for mobile upward

λ_n : λ for non-real-time service

The relationship among the variables is as follows:

$\lambda_r << \lambda_n << \lambda_u$ -- (1)

5.2 Control Mechanism of Handoff

In real-time service, the handoff delay must be short in the handoff transition region, therefore the number of continuous beacon signal should be lower than that of the non real- time service in order to reduce handoff delay. Since the CDMA cellular network covers a wide area and the handoff time is not critical for the MU, the value of λ_n should be higher than other values. To reduce overall handoff delay, the in-bound packets are multicasted to the SA of the target network by mobility management. They are multicasted when the beacon signal strength in the MD falls below the λ_{thresh} or rises higher than the λ_{thresh} in MU. The multicasted data are buffered in the SA. These buffered data will be transmitted to the BS if the MH is handed off to the target network before the timer expires. Otherwise, those data will be discarded. During the periodic the MH checks of the RSS of the received beacon signals, if the RSS falls below λ_{thresh}, λ is increased by one. The MH determines whether the handoff should take place or not by comparing λ_r, λ_n with the increased λ. The control mechanism of the handoff is shown in Figure5.4.

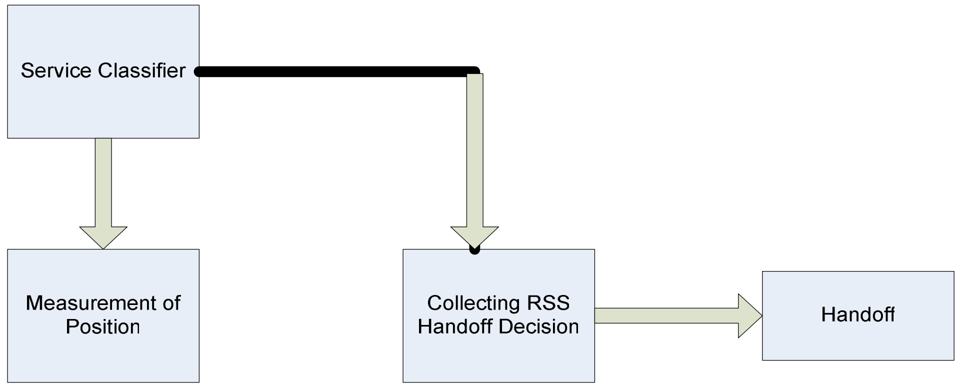

Figure 5.4 Control Mechanism of Handoff

First, the service classifier classifies the traffic as either real-time service, and then it sends the control signal to the handoff decision block and the measurement block. The power strength of the beacon signal in the transition region as the MH moves from the coverage of the WLAN to outside coverage shown in Figure5.5 [11]:

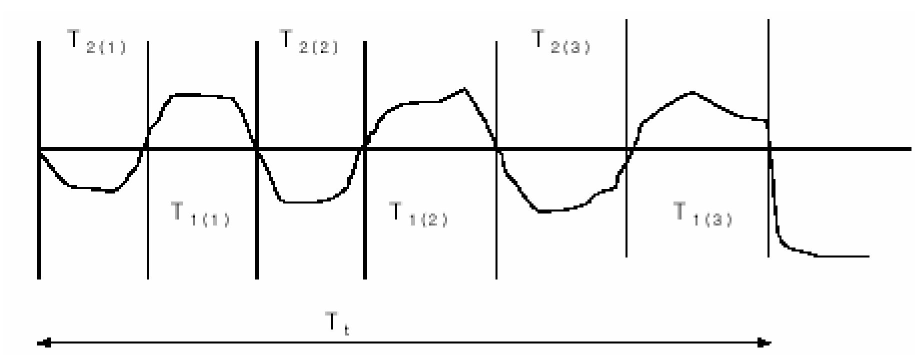

Figure 5.5 Transition Region

The following variables are used to deduce handoff delay and throughput as the MH moves around the handoff transition region.

T_t : Region extending from the point at which the power P falls below λ_{thresh} for the first time permanently.

T_1 : Each contiguous stretch of time where $P > \lambda_{thresh}$ within T_t

T_2 : Each contiguous stretch of time where $P < \lambda_{thresh}$ within T_t

T_N : Normalized handoff delay in handoff transition region

S(i) : Average throughput in each case

N : Number of times P crosses the value of

Δ : Handoff Completion time

R_1 : Effective data rate available over the air in the WLAN

R_2 : Effective data rate available over the air in the CDMA Cellular Network.

6. Simulation and Implementation of Handoff algorithm

In this chapter we describe how the Vertical Handoff Algorithm was implemented and how the simulation was carried out. It is important that we test the performance of the algorithm by simulating it over a wide range of simulation parameters. This is true not only for the Vertical Handoff Algorithm but as a matter of fact, for any algorithm. Simulation firstly, helps us determine whether the algorithm is performing correctly as required by the standards and the user. Before the algorithm is implemented in real time systems, its performance has to be carefully studied so that, the system in which the algorithm is implemented performs according to the users expectations.

Secondly, this simulation also helps us determine the right values of the parameters that need to be set so that the algorithm attains a satisfactory performance level. If the parameters are not appropriately set then it may happen that the algorithm might be switching too often between the two networks without any real necessity for doing it and thus, causing a sub-optimal performance of the system/device; or it might also happen that the algorithm does not switch the device connection between networks even though the device might perform better in the other network.

Thus, it is very important that we test the algorithm using simulation in order to determine its effectiveness when used in real world devices and to find the right parametersof the algorithm so that its performance is optimized. We start off this chapter by describing the code and the inputs required and how the code operates. In the next section we present some results and analyze the plots so obtained. Finally, we present the conclusions drawn from our simulation study.

6.1 Code Structure and Description

The code structure shown in Figure6.1 is self explanatory, but for the sake of clarity it is elaborated in this section. Refer Appendix A for Code. The code requires a set of input values for the parameters (Appendix B), for example, the value of “threshold signal”, which is the value of signal strength. Any signal having strength less than this threshold value is considered weak and any signal having strength greater than the threshold value is considered as strong. We can also choose to set the user in any of the networks at the start of the simulation. Obviously in real world whether the user is working in a network is determined by the position of the user or the position of his device to be more precise. Also simulation is carried on for a specific period of time. For speeding up the simulation process, time has been converted to number of iterations. At the start of any iteration the signal strength is measured.

If the user is working in WLAN at the start of the simulation, the simulation is carried out as described below. The signal strength is determined by randomly generating a value that lies between a predetermined lower and upper bounds that are to be set by us. Once the signal strength is determined we need to determine whether the user is working in real-time or non real-time. This is done by randomly generating either 0 or 1 with equal probability. If the user works in real time then it might be better if the user receives strong signals more frequently than while working in non real-time. Once we determine whether the user works in real-time or non real-time, we measure the number of times the user/device receives a weak signal. If the weak signal frequency exceeds a preset value the user/device will be connected to CDMA network. If during any process the user/device receives a strong signal the weak signal count will be reset and the user continues to operate in WLAN network.

Refer Appendix C for sample results.

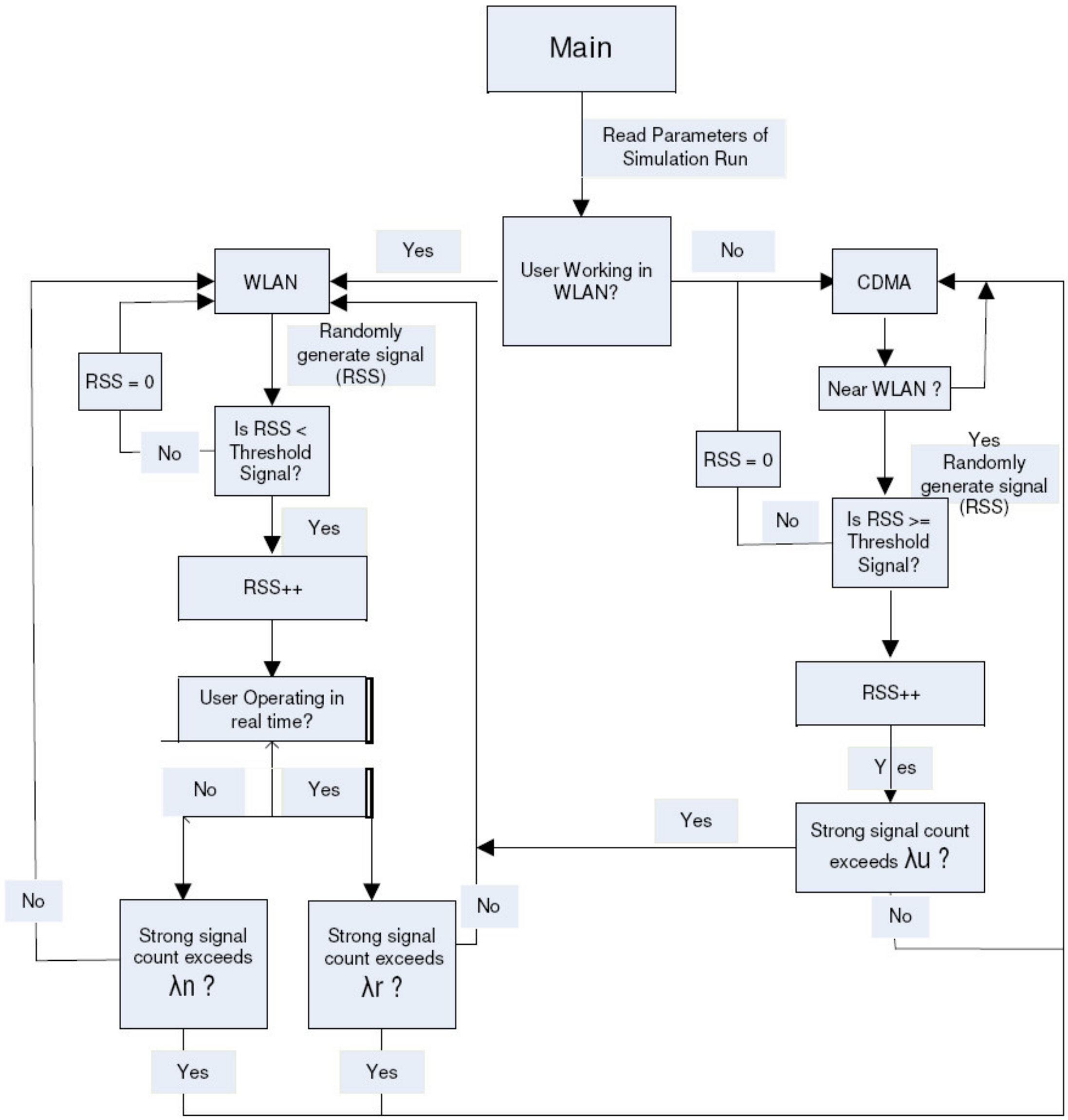

Figure 6.1 Structure of the C code that runs the Simulation

If the user starts working in CDMA, we first need to determine whether the user is near a WLAN network or not before measuring the signal strength. In real-time we incur some cost in terms of system/device resource utilization each time we measure the signal strength, so we do not want to waste the resources of the device to measure the signal strength unnecessarily and hence we measure the signal strength only if the user/device is near WLAN network. If the user is not anywhere near WLAN network then obviously there is no point for him to try and connect to the WLAN as he will be receiving a weak signal, and hence the user/device will continue to work in CDMA in this case.

In case the user is working near WLAN we measure the strength of the signal and if the strength exceeds the threshold value, the user/device is receiving a strong signal, so we increase our strong signal count. If the strong signal count exceeds a preset value, we switch over to WLAN since the user/device is reliably receiving a strong signal and it would be sub-optimal to be still working in CDMA. If the strong signal count does not exceed we go back to simulation point where we start off working in CDMA network.

In addition to determining all the parameters that are described above, it is also of utmost importance that we determine a right value for the interval in which we measure the signal strength. If we measure the signal strength too often we might be over utilizing the system/device resources just for executing the Vertical Handoff Algorithm. If we do not measure the signal strength for long durations of time, the user/device might continue to work in a network where it would be very inefficient for it even though it might be optimal to work in an alternative network.

6.2 Results

In this section we will describe and analyze the results. We have tested the performance of the algorithm over a varied range of simulation parameters. We present some of the results in the plots below and analyze each plot individually.

In the plot shown in Figure6.2, we have plotted the threshold value of the signal strength against the time spent in WLAN network. It shows that as the threshold value increases the time spent in WLAN decreases. This is because the user/device criterion for a strong signal increases, forcing most of the signal strength measurements to be weak and hence the user switches to CDMA and spends more time in CDMA network. We find an anomaly when the threshold value is 30, this is because our simulation is multi parameter based and affects other parameters shows up at this particular signal strength.

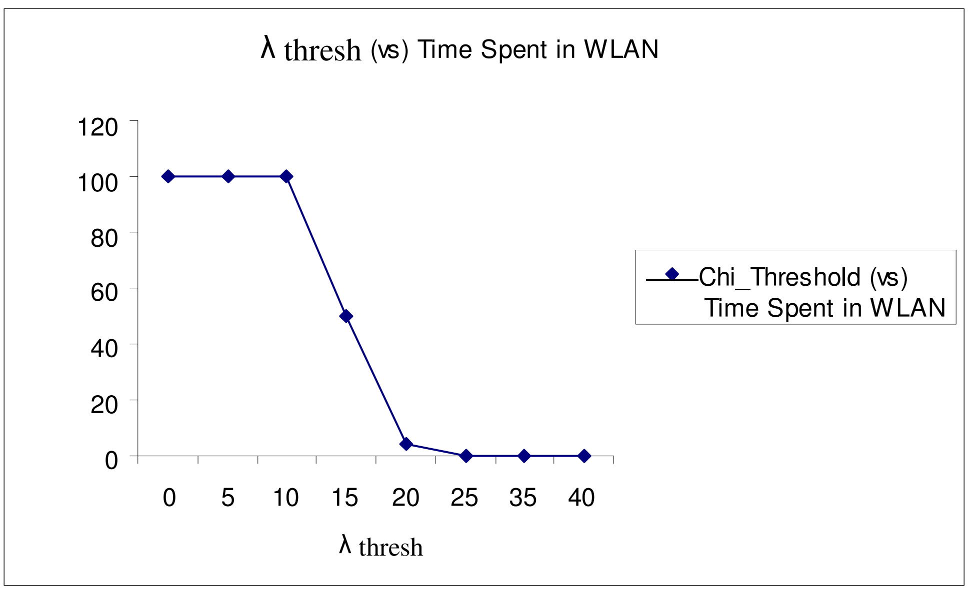

Figure 6.2 Plot of λ thresh (vs) Time Spent in WLAN

In the plot shown in Figure6.3, we have plotted the threshold value of the signal strength against the time spent in CDMA network. It shows that as the threshold value increases the time spent in CDMA increases. This is because the user/device criterion for a strong signal increases, forcing most of the signal strength measurements to be weak and hence the user switches to CDMA and spends more time in CDMA network. We find an anomaly when the threshold value is 30, this is because our simulation is multi parameter based and the effect other parameters shows up at this particular signal strength.

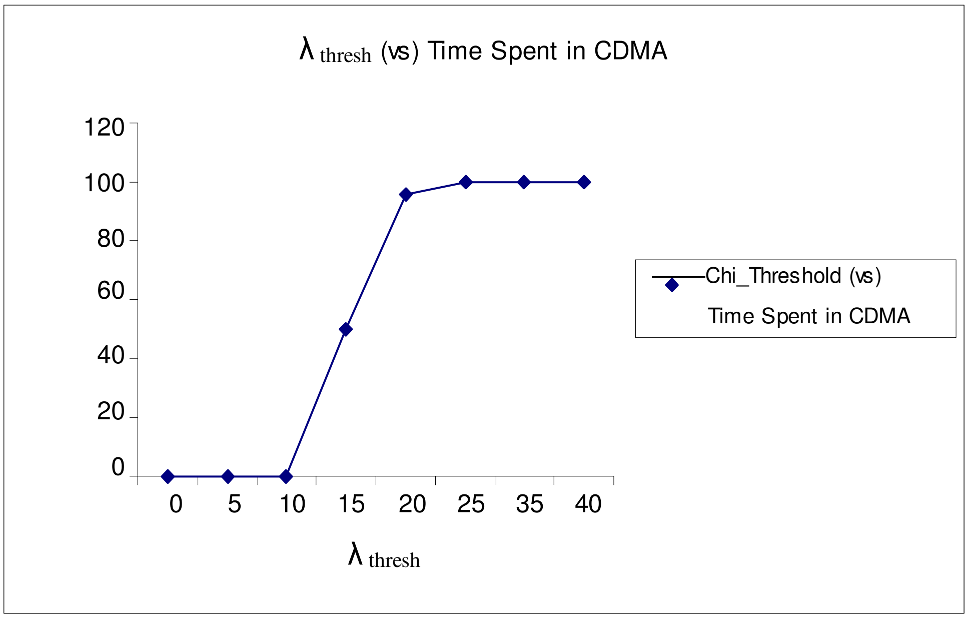

Figure 6.3 Plot of λ thresh (vs) Time Spent in CDMA

In the plot shown in Figure 6.4, we have plotted the value of weak signal count if operating in real time required for switching to CDMA network (λr) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for weak signals easily exceeds λr value and hence the user switches to CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

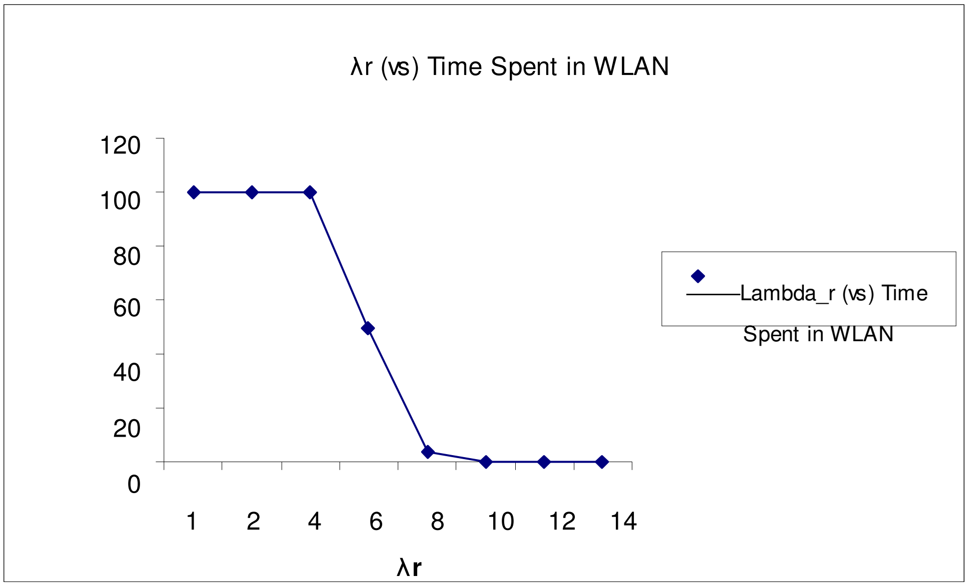

Figure 6.4 Plot of λr (vs) Time Spent in WLAN

In the plot shown in Figure6.5, we have plotted the value of strong signal count required for switching to WLAN network (λu) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for strong signals is difficult to exceed λu value and hence the user continues to operate in CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

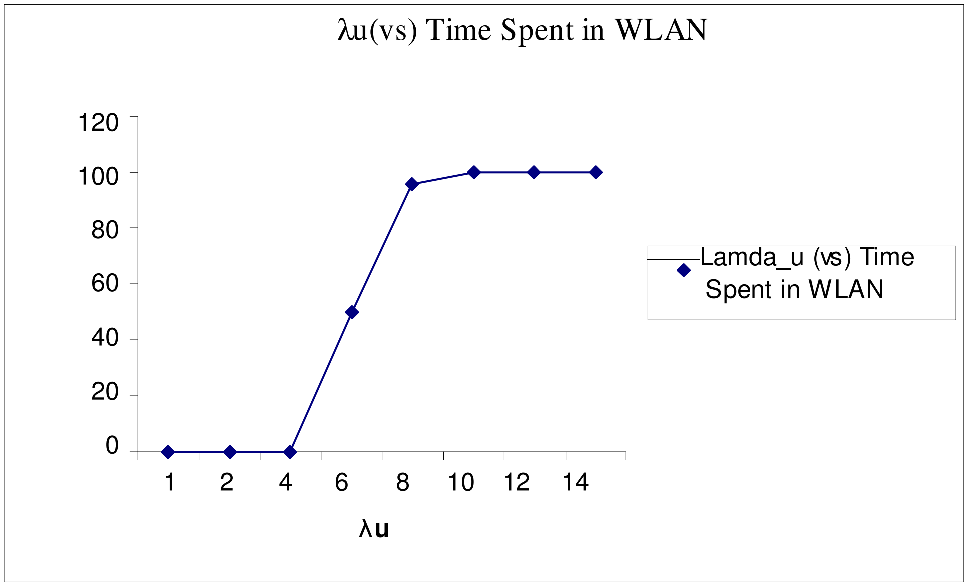

Figure 6.5 Plot of λu (vs) Time Spent in WLAN

In the plot shown in Figure 6.6, we have plotted the value of weak signal count if operating in non real time required for switching to CDMA network (λn) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for weak signals easily exceeds λn value and hence the user switches to CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

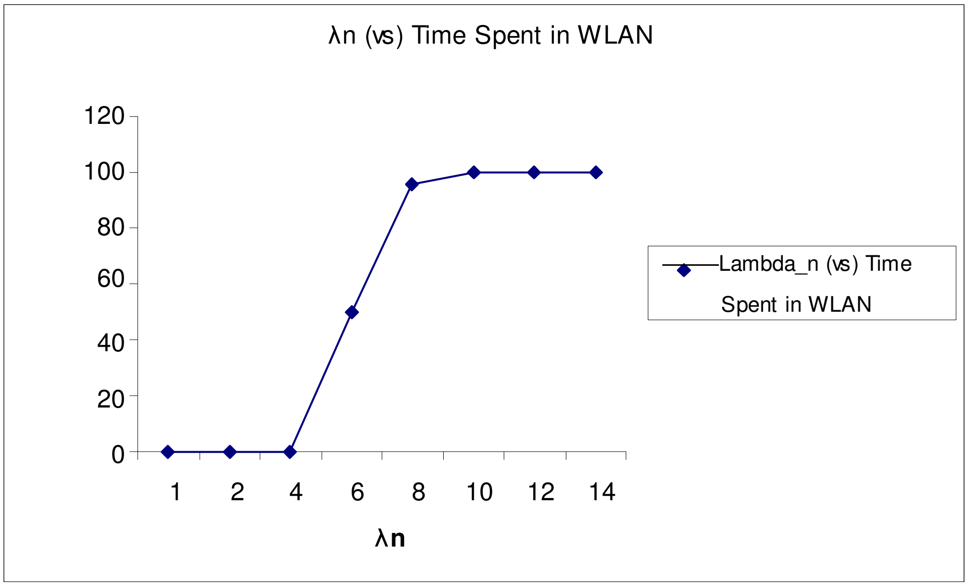

Figure 6.6 Plot of λn (vs) Time Spent in WLAN

In the plot shown in Figure6.7, we have plotted the value of weak signal count if operating in real time required for switching to CDMA network (λr) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for weak signals easily exceeds λr value and hence the user switches to CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

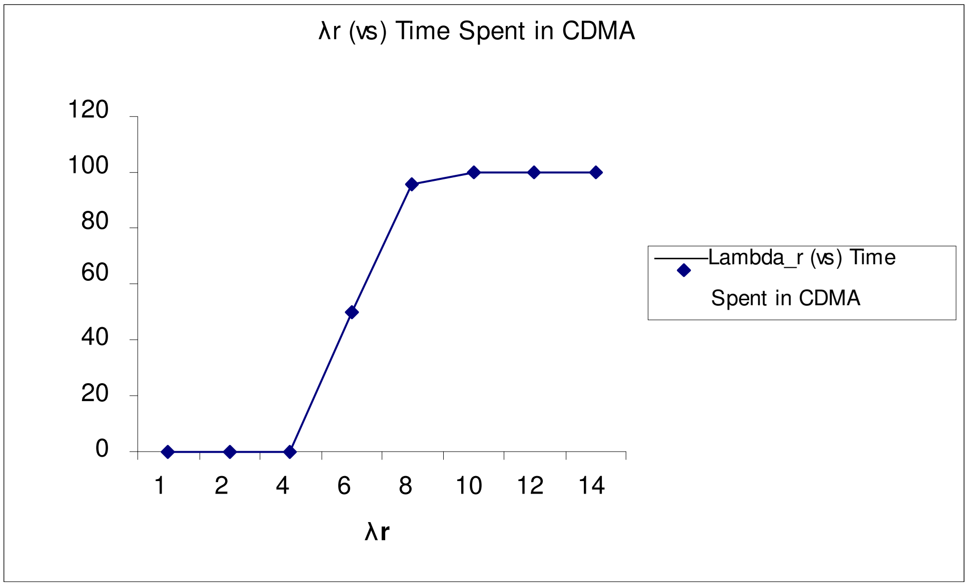

Figure 6.7 Plot of λr (vs) Time Spent in CDMA

In the plot shown in Figure6.8, we have plotted the value of strong signal count required for switching to WLAN network (λu) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for strong signals is difficult to exceed λu value and hence the user continues to operate in CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

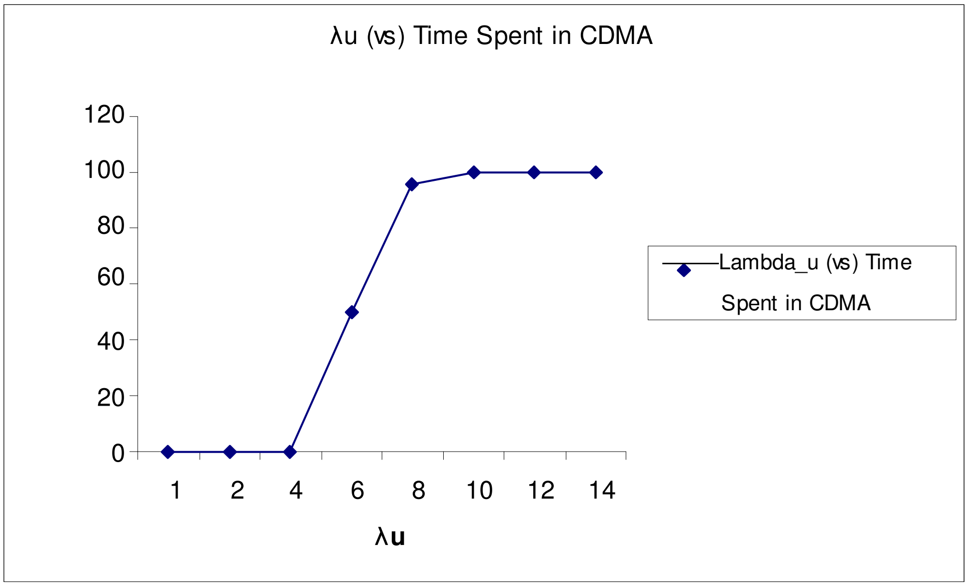

Figure 6.8 Plot of λu (vs) Time Spent in CDMA

In the plot shown in Figure6.6, we have plotted the value of weak signal count if operating in non real time required for switching to CDMA network (λn) against the time spent in WLAN network. The plot shows that as this value increases the time spent in WLAN decreases. This is because the user/device count for weak signals easily exceeds λn value and hence the user switches to CDMA network. This result also depends on the interactions of other parameters as well, for example, if the threshold value had been low then the user would be forced to switch a number of times between CDMA and WLAN networks, thus spending almost the same amount of time in each network.

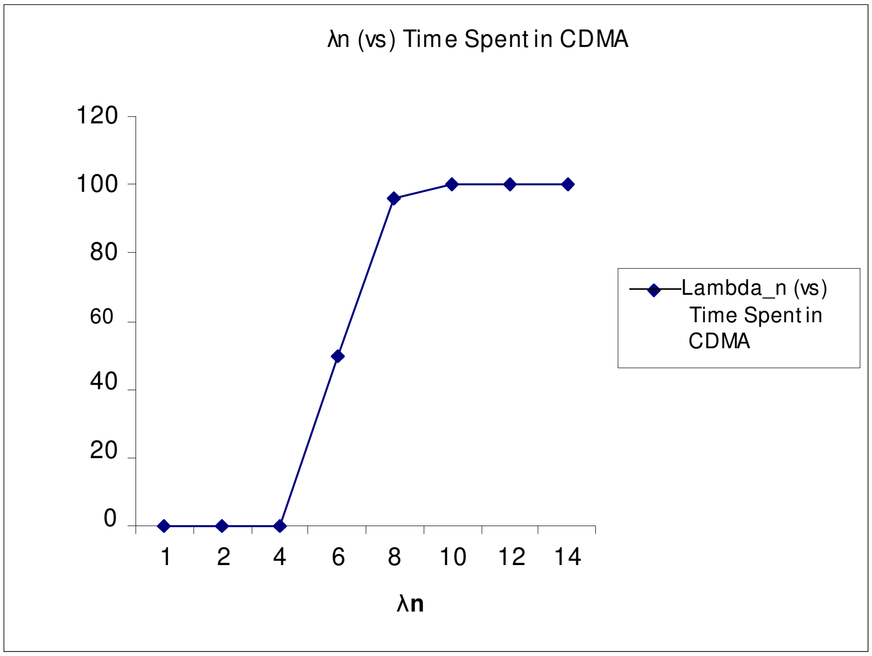

Figure 6.9 Plot of λn (vs) Time Spent in CDMA

7. Conclusion

An implementation of a seamless vertical handoff procedure and the effective handoff algorithm for the handoff transition region between the WLAN and CDMA cellular network is presented. In chapter 6, we have gone extensively about the various parameters that govern the smooth functioning of the algorithm and how they affect the time spent in WLAN and CDMA networks. The algorithm, as shown by the simulation results, does not result in too many switches between the WLAN and CDMA networks and hence would provide quite a useful tool for the device in real time functioning.

Nevertheless the algorithm has some drawbacks. One major drawback is that if the parameters are not chosen rightly the algorithm would result in an inefficient usage of resources and a sub-optimal performance of the device into which the algorithm is loaded. Second drawback, which can be considered as an extension of the first one, is that if that the algorithm might reset the strong or weak signal counts just before they reach their maximum limit and thus resulting in the user operating in an inefficient network. A more robust algorithm would also consider the number of times this reset has taken place and would correspondingly switch between the networks. But in spite of these drawbacks if the parameters are chosen correctly the algorithm can perform quite efficiently and a maximum performance can be extracted from the device given an operating environment.

Mobility management using MA and SA was also adopted to minimize the handoff delay in the WLAN-CDMA Cellular interconnection architecture based on IP. In the handoff algorithm number of continuous beacon signals are used whose signal strength from the WLAN falls below the predefined threshold value. But when the value of parameters are increased like in Figure 6.2 when the value of λ_{thresh} is increased, the time spent in CDMA network increases even though there is a strong signal count from WLAN network, which should be avoided.

The traffic is classified into real-time service and non real-time service. In real-time service, the handoff delay in the handoff transition region must be short, so the number of continuous beacon signals should be lower than that of the non real-time service in order to reduce handoff delay. The value of λu is considered to be higher than the other values as the CDMA cellular network covers a wide area and the handoff time is not critical in MU.

The assumption that the load of the WLAN and the CDMA cellular networks is nominal for the purpose of simplification is made in analyzing the average throughput and handoff delay. The average throughput is improved in non real-time service through the analysis formula. The handoff delay is improved in real-time service.We simulated suitable variables of λ_r, λ_n, λ_u. In the future study, one might need to study the effect of the proposed scheme on real world applications by developing a more sophisticated simulation model for the wireless networks.

Handoff delay poses an important QoS-related issue in 4G wireless networks. Although likely to be smaller intranetwork handoffs, the delay can be problematic in internetwork handoffs because of authentication procedures that require message exchange, multiple-database accesses, and negotiation-renegotiation due to a significant difference between needed and available QoS [18]. During the handoff process, the user may experience a significant drop in QoS that will affect the performance of both upper-layer protocols and applications. Deploying a priority-based algorithm and using location-aware adaptive applications can reduce both handoff delay and QoS variability.

When there is a potential for considerable variation between senders' and receivers' device capabilities, deploying a receiver-specific filter in part of the network close to the source can effectively reduce the amount of traffic and processing, satisfying other users' QoS needs. Although 4G wireless technology offers higher bit rates and the ability to roam across multiple heterogeneous wireless networks, several issues require further research and development.

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Appendix – A

C code for simulating the handoff algorithm:

```
/*******************************************************\
*
*
* Author       : Mary Narisetti
*
* Application  : This code simulates the vertical handoff algorithm for *
4g networks
*
*
\*******************************************************/


 /* Includes the library functions of C */

#include <stdio.h>
#include <stdlib.h>
#include <memory.h>
#include <ctype.h>
#include <string.h>
#include <math.h>
#include <time.h>

 /* Declaration of Global Variables for time control of Simulation */

  time_t  start, end;

 /* For scaling the time in order quicked the simulation */

  int     scale_time    = 0;
  int     scale_measure = 0;

 /* Seed for generating random numbers */

  long  *seed;

 /* For keeping count of the changes to different networks and time
spent in each network */

  int count_wlan = 0;
  int count_cdma = 0;
  int wlan_cdma  = 0;

 /* Opens the file for writing the solution */

 FILE *fpt = fopen("SimulationResults.txt", "wb");
```

```
 /* Function for reading data from file */

int readln(FILE *fp, char *ch)
{
  char c;
  int i = 0;
  if (fread(&c, 1, 1, fp)<1)
   return 0;
  while (c=='\n' || c=='\r' || c==' ')
   if (fread(&c, 1, 1, fp)<1)
    return 0;
  while (!(c=='\n' || c == '\r'))
   {
    *ch = c;
     ch++;
     i++;
     if (fread(&c, 1, 1, fp)<1)
      return 0;
   }
 *ch=0;
  return 1;
}
 /* END readln */

 /* Random number generator functions */

/*******************************************************************
Function: rndnum
Portable uniform (0,1) random number generator.  Uses the
multiplicative congruential method:
z(i)=(7**5*z(i-1))(mod 2**31 - 1)
Ref : Law & Kelton, SIMULATION MODELING AND ANALYSIS,
McGraw Hill, 1982, p. 227.
*******************************************************************/
double rndnum(
long  *seed )                /* long integer seed (by reference) */
{
   static long  a = 16807;
   static long  b15 = 32768;
   static long  b16 = 65536;
   static long  p = 2147483647;
   static long  xhi, xalo, leftlo, fhi, k;
   static double lawkel;

   xhi = *seed/b16;
   xalo = ( *seed - xhi * b16) * a;
   leftlo = xalo / b16;
   fhi = xhi * a + leftlo;
   k = fhi / b15;
   *seed = ( ( ( xalo - leftlo * b16 ) - p )+( fhi - k * b15 ) * b16 ) +
k;
   if ( *seed < 0 ) *seed = *seed + p;
   lawkel = *seed * 4.656612875e-10;

   return lawkel;
}
```

```
/***************************************************************
Function: drand
Generate a (continuous) uniform random variable in the
interval [a,b] using a passed seed.  Returns the value.
***************************************************************/
double drand(
double a,                 /* low end of the range */
double b,                 /* high end of the range */
long  *seed )             /* long integer seed (by reference) */
{
   double value;

   value = (a + (b - a) * rndnum(seed));
   return value;
}

/***************************************************************
Function: irand
Generate an integer uniform random variable in the (integer)
interval [a,b] using a passed seed.  Returns the value.
***************************************************************/
int irand(
int a,                      /* low end of the range */
int b,                      /* high end of the range */
long *seed )                /* long integer seed (by reference) */
{
   int trial;

   trial = a + (int) ( (b - a + 1) * rndnum(seed) );
   if (trial > b)
   {
      trial = b;
   }
   return trial;
}


 /* Declaration of functions that will be used */

int loop_wlan(double Chi_thresh, int real_time, int lambda_r, int
lambda_n, int Num_RSS, double RSS, int NEARWLAN, int lambda_u, int
Sim_time, int Mea_time);
int loop_cdma(int NEARWLAN, double Chi_thresh, int lambda_u, int Num_RSS,
double RSS, int real_time, int lambda_r, int lambda_n, int Sim_time, int
Mea_time);

int loop_cdma1(int NEARWLAN, double Chi_thresh, int lambda_u, int
Num_RSS, double RSS, int real_time, int lambda_r, int lambda_n, int
Sim_time, int Mea_time);


 /* Main starts here */

int main()
{
```

```
/* Declaration of Variables and Parameters */

double RSS        = 0;
double Chi_thresh = 0;
int Num_RSS       = 0;
int WORKWLAN      = 0;
int NEARWLAN      = 0;
int real_time     = 0;
int lambda        = 0;
int lambda_r      = 0;
int lambda_n      = 0;
int lambda_u      = 0;
int Sim_time      = 0;
int Mea_time      = 0;

/* Declaration of all purpose variables */

char chn[100];
char *tchn;
int i        = 0;
int j        = 1;
int read     = 0;
double read1 = 0;


 seed = (long *)malloc(1*sizeof (long));
 *seed = 1093938;

/* Reads initial input values from file Parameters.txt */

FILE *fpn = fopen("Parameters.txt", "rb");
 while(!feof(fpn) && j==1)
 {
   j++;
   readln(fpn,chn);
   tchn=chn+44;
   while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
   sscanf(tchn,"%d",&read);
   WORKWLAN=read;
   readln(fpn,chn);
   tchn=chn+44;
   while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
   sscanf(tchn,"%d",&read);
   NEARWLAN=read;
   readln(fpn,chn);
   tchn=chn+44;
   while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
   sscanf(tchn,"%lf",&read1);
   Chi_thresh=read1;
   readln(fpn,chn);
   tchn=chn+44;
   while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
   sscanf(tchn,"%d",&read);
   real_time=read;
   readln(fpn,chn);
   tchn=chn+44;
   while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
   sscanf(tchn,"%d",&read);
   lambda_r=read;
```

```
    readln(fpn,chn);
    tchn=chn+44;
    while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
    sscanf(tchn,"%d",&read);
    lambda_n=read;
    readln(fpn,chn);
    tchn=chn+44;
    while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
    sscanf(tchn,"%d",&read);
    lambda_u=read;
    readln(fpn,chn);
    tchn=chn+44;
    while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
    sscanf(tchn,"%d",&read);
    Sim_time=read;
    readln(fpn,chn);
    tchn=chn+44;
    while (*tchn==' ' || *tchn=='\r' || *tchn=='\n') tchn++;
    sscanf(tchn,"%d",&read);
    Mea_time=read;

   } fclose(fpn);

  /* Takes the measurement this many times */
  scale_measure = Sim_time/Mea_time;

  /* Gets Start time of Simulation */

  time(&start);



  /* Writes the input values of the Simulation */

  fprintf(fpt,"\n INPUT VALUES OF THE SIMULATION \n");
  fprintf(fpt," -------------------------------- \n");

  fprintf(fpt,"Working in WLAN : 1 for yes : 0 for no : %d \n", WORKWLAN);
  fprintf(fpt,"Near WLAN if working in CDMA           : %d \n", NEARWLAN);
  fprintf(fpt,"Value of Chi_thresh                    : %lf
\n",Chi_thresh);
  fprintf(fpt,"Service Class realtime if 1 else 0     : %d \n",real_time);
  fprintf(fpt,"Value of lambda_r                      : %d \n",lambda_r);
  fprintf(fpt,"Value of lambda_n                      : %d \n",lambda_n);
  fprintf(fpt,"Value of lambda_u                      : %d \n",lambda_u);
  fprintf(fpt,"Total Simulation Time in Seconds       : %d \n",Sim_time);
  fprintf(fpt,"Signal Measuring Interval in Seconds   : %d \n",Mea_time);


  fprintf(fpt," -------------------------------- \n");

  fprintf(fpt,"\n \n -------------------------------- \n");
  if ( WORKWLAN == 1 )
    fprintf(fpt," Working in WLAN at the start of Simulation \n");
  else
    {
```

```
  fprintf(fpt," Working in CDMA at the start of Simulation \n");
     if ( NEARWLAN == 1 )
       fprintf(fpt," User located near WLAN \n");
     else
       fprintf(fpt," User not located near WLAN \n");
   }
 fprintf(fpt," -------------------------------- \n");


 /* Goes to the appropriate function i.e., whether working in WLAN or
CDMA */

 if(WORKWLAN == 1)
  loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
 else
  loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);

 fprintf(fpt," -------------------------------- \n");
 fprintf(fpt,"\n\n\n SIMULATION STATISTICS \n");
 fprintf(fpt," -------------------------------- \n");
 fprintf(fpt," Time spent in WLAN network     : %d seconds
\n",(count_wlan*Mea_time));
 fprintf(fpt," Time spent in CDMA network     : %d seconds
\n",(count_cdma*Mea_time));
 fprintf(fpt," Changes between WLAN and CDMA  : %d \n",wlan_cdma);
 fprintf(fpt," -------------------------------- \n\n\n");


 fprintf(fpt," -------------------------------- \n");
 fprintf(fpt," Simulation Ended Successfully \n");
 fprintf(fpt," -------------------------------- \n");

 fclose(fpt);
 return 0;
}

 /* End of main() */

 /* Start of WLAN function of the algorithm */

int  loop_wlan(double Chi_thresh, int real_time, int lambda_r, int
lambda_n, int Num_RSS, double RSS, int NEARWLAN, int
lambda_u, int Sim_time, int Mea_time)
{

 /* Gets end time of Simulation */

  time(&end);

  count_wlan++;
  scale_time++;
  /* Carries the simulation for Sim_time */
  if( scale_time >= scale_measure)
   return 0;
```

```
 /* Declaration of Variables */

  double a = 10;
  double b = 25;
  double check;
  time_t  now, later;


 fprintf(fpt," ------------------------------- \n");
 fprintf(fpt,"\n User working in WLAN \n");


 /* Measurement of RSS: Randomly generated */

  RSS = drand(a,b,seed);

  fprintf(fpt,"\n Generated Value of RSS: %lf \n", RSS);
  if(RSS < Chi_thresh)
  {
   Num_RSS++;
   fprintf(fpt,"\n RSS signal is less than Chi_threshold \n");
   fprintf(fpt,"\n Weak Signal count: %d \n",Num_RSS);
   if(real_time == 1)
   {
    fprintf(fpt,"\n Operating in Real time in WLAN \n");
    if(Num_RSS >= lambda_r)
    {
     Num_RSS = 0;
     fprintf(fpt, "\n Weak Signal count exceeds lambda_r: User connects
to CDMA \n");
     wlan_cdma++;
     loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
    }
    else
    {
     fprintf(fpt,"\n Weak Signal count does not exceed lambda_r: User
still works in WLAN \n");
     loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
    }
   }
   else
   {
    fprintf(fpt,"\n Not Operating in Real time in WLAN \n");
    if(Num_RSS >= lambda_n)
    {
     Num_RSS = 0;
     fprintf(fpt, "\n Weak Signal count exceeds lambda_n: User connects
to CDMA \n");
     wlan_cdma++;
     loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
    }
    else
    {
```

```
 fprintf(fpt,"\n Weak Signal count does not exceed lambda_n: User still
works in WLAN \n");
     loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
    }
   }
  }
  else
  {
   Num_RSS = 0;
   fprintf(fpt,"\n Signal strong so Count reset: User Continues to work
in WLAN \n");
   loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
  }
}

 /* End of WLAN function */

 /* Start of CDMA function of the algorithm */

int  loop_cdma(int NEARWLAN, double Chi_thresh, int lambda_u, int
Num_RSS, double RSS, int real_time, int lambda_r, int
lambda_n, int Sim_time, int Mea_time)
{

 /* Gets end time of Simulation */

  time(&end);

  count_cdma++;
  scale_time++;
  /* Carries the Simulation for Sim_time seconds */
  if( (scale_time) >= scale_measure)
   return 0;

  /* Declaration of Variables */

  double a = 10;
  double b = 25;
  double check;
  time_t  now, later;


 fprintf(fpt," -------------------------------- \n");
 fprintf(fpt,"\n User working in CDMA \n");


 /* Generate NEARWLAN randomly */

  NEARWLAN = irand(0,1,seed);

  if(NEARWLAN == 1)
  {

  fprintf(fpt,"\n User working in region near WLAN \n");
 /* Measurement of RSS: Randomly generated */
```

```
 RSS = drand(a,b,seed);

   fprintf(fpt,"\n Generated Value of RSS: %lf \n", RSS);

   if(RSS > Chi_thresh)
   {
    Num_RSS++;
    fprintf(fpt,"\n RSS signal is greater than Chi_threshold \n");
    fprintf(fpt,"\n Strong Signal count: %d \n",Num_RSS);
    if(Num_RSS >= lambda_u)
    {
     Num_RSS = 0;
     fprintf(fpt, "\n Strong Signal count exceeds lambda_u: User connects
to WLAN \n");
     wlan_cdma++;
     loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
    }
    else
    {
     fprintf(fpt, "\n Strong Signal count does not exceed lambda_u: User
still works in CDMA \n");
     loop_cdma1(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
    }
   }
   else
   {
    Num_RSS = 0;
    fprintf(fpt, "\n Signal Weak Strong signal count reset: User still
works in CDMA \n");
    loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
   }
  }
  else
  {
   fprintf(fpt,"\n User is not working in region near WLAN \n");
   loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
  }


}

 /* End of CDMA function */

 /* Start of CDMA1 function of the algorithm */

int  loop_cdma1(int NEARWLAN, double Chi_thresh, int lambda_u, int
Num_RSS, double RSS, int real_time, int lambda_r, int
lambda_n, int Sim_time, int Mea_time)
{
 /* Gets end time of Simulation */
```

```
time(&end);

  count_cdma++;
  scale_time++;
 /* Carries the Simulation for Sim_time seconds */
  if( (scale_time) >= scale_measure)
   return 0;

 /* Declaration of Variables */

  double a = 10;
  double b = 25;
  double check;
  time_t  now, later;


  fprintf(fpt," -------------------------------- \n");
  fprintf(fpt,"\n User working in CDMA \n");


 /* Measurement of RSS: Randomly generated */

   RSS = drand(a,b,seed);
   fprintf(fpt,"\n Generated Value of RSS: %lf \n", RSS);

   if(RSS > Chi_thresh)
   {
    Num_RSS++;
    fprintf(fpt,"\n RSS signal is greater than Chi_threshold \n");
    fprintf(fpt,"\n Strong Signal count: %d \n",Num_RSS);
    if(Num_RSS >= lambda_u)
    {
     Num_RSS = 0;
     fprintf(fpt, "\n Strong Signal count exceeds lambda_u: User connects
to WLAN \n");
     wlan_cdma++;
     loop_wlan(Chi_thresh, real_time, lambda_r, lambda_n, Num_RSS, RSS,
NEARWLAN, lambda_u, Sim_time, Mea_time);
    }
    else
    {
     fprintf(fpt, "\n Strong Signal count does not exceed lambda_u: User
still works in CDMA \n");
     loop_cdma1(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
    }
   }
   else
   {
    Num_RSS = 0;
    fprintf(fpt, "\n Signal Weak Strong signal count reset: User still
works in CDMA \n");
    loop_cdma(NEARWLAN, Chi_thresh, lambda_u, Num_RSS, RSS, real_time,
lambda_r, lambda_n, Sim_time, Mea_time);
   }
}
/* End of CDMA1 function */
```

Appendix – B

Input file for the C code:

```
Working in WLAN (1 for yes : 0 for no)    :   1
Near WLAN if working in CDMA              :   0
Value of Chi_thresh                       :   30
Service Class realtime: 1 else 0          :   1
Value of λr                         :   1
Value of λn                          :   1
Value of lambda_u                         :   20
Total Simulation Time in Seconds          :   60
Signal Measuring Interval in Seconds      :   10
```

Appendix – C

Sample results of the simulation:

Sample Result 1:

```
INPUT VALUES OF THE SIMULATION
 --------------------------------
Working in WLAN : 1 for yes : 0 for no : 1
Near WLAN if working in CDMA           : 0
Value of Chi_thresh                    : 30.000000
Service Class realtime if 1 else 0     : 1
Value of λ                             : 2
Value of λn                            : 1
Value of lambda_u                      : 20
Total Simulation Time in Seconds       : 100
Signal Measuring Interval in Seconds   : 10
 --------------------------------



 --------------------------------
 Working in WLAN at the start of Simulation
 --------------------------------
 --------------------------------

 User working in WLAN

 Generated Value of RSS: 18.423441

 RSS signal is less than Chi_threshold

 Weak Signal count: 1

 Operating in Real time in WLAN

 Weak Signal count does not exceed λr: User still works in WLAN
 --------------------------------

 User working in WLAN

 Generated Value of RSS: 12.773286

 RSS signal is less than Chi_threshold

 Weak Signal count: 2
```

```
Operating in Real time in WLAN

Weak Signal count exceeds λr: User connects to CDMA
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA

User working in region near WLAN

Generated Value of RSS: 14.892403

Signal Weak Strong signal count reset: User still works in CDMA
--------------------------------

User working in CDMA

User working in region near WLAN

Generated Value of RSS: 23.400587

Signal Weak Strong signal count reset: User still works in CDMA
--------------------------------

User working in CDMA

User working in region near WLAN

Generated Value of RSS: 12.274121

Signal Weak Strong signal count reset: User still works in CDMA
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA
```

```
User is not working in region near WLAN
--------------------------------



SIMULATION STATISTICS
--------------------------------
Time spent in WLAN network     :  20  seconds
Time spent in CDMA network     :  80  seconds
Changes between WLAN and CDMA  : 1
--------------------------------


--------------------------------
Simulation Ended Successfully
--------------------------------
```

Sample Result 2:

```
 INPUT VALUES OF THE SIMULATION
 --------------------------------
Working in WLAN : 1 for yes : 0 for no : 0
Near WLAN if working in CDMA           : 1
Value of Chi_thresh                    : 20.000000
Service Class realtime if 1 else 0     : 1
Value of λr                            : 1
Value of λn                            : 2
Value of lambda_u                 : 2
Total Simulation Time in Seconds       : 100
Signal Measuring Interval in Seconds   : 10
 --------------------------------


 --------------------------------
 Working in CDMA at the start of Simulation
 User located near WLAN
 --------------------------------
 --------------------------------

 User working in CDMA

 User working in region near WLAN

 Generated Value of RSS: 12.773286
```

```
Signal Weak Strong signal count reset: User still works in CDMA
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA

User working in region near WLAN

Generated Value of RSS: 14.892403

Signal Weak Strong signal count reset: User still works in CDMA
--------------------------------

User working in CDMA

User working in region near WLAN

Generated Value of RSS: 23.400587

RSS signal is greater than Chi_threshold

Strong Signal count: 1

Strong Signal count does not exceed lambda_u: User still works in CDMA
--------------------------------


User working in CDMA

Generated Value of RSS: 23.659622

RSS signal is greater than Chi_threshold

Strong Signal count: 2

Strong Signal count exceeds lambda_u: User connects to WLAN
--------------------------------

User working in WLAN

Generated Value of RSS: 12.274121

RSS signal is less than Chi_threshold
```

```
Weak Signal count: 1

Operating in Real time in WLAN

Weak Signal count exceeds λr: User connects to CDMA
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

User working in CDMA

User is not working in region near WLAN
--------------------------------

SIMULATION STATISTICS
--------------------------------
Time spent in WLAN network     :  10  seconds
Time spent in CDMA network     :  90  seconds
Changes between WLAN and CDMA  : 2
--------------------------------
----------------------
Simulation Ended Successfully
--------------------------------
```